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Converting Rock Trickling Filters to Plastic Media: Design and Performance

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Walnut Creek, CA

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Research and Development

Converting Rock Trickling Filters to Plastic Media

Design and Performance

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August 1980

CONVERTING ROCK TRICKLING FILTERS TO PLASTIC MEDIA

Design and Performance

by

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Contract No. 68-03-2349

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report summarizes background considerations, process and physical design details, secondary system construction and startup experiences, and 1 yr of operating and performance data for conversion of three existing rock media trickling filters to the world's largest plastic media trickling filters. The information documented herein is recommended reading for design engineers, facilities planners, and potential municipal users of attached growth biological wastewater treatment systems.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This investigation was undertaken with the objectives of reviewing the conversion of trickling filters at the Stockton, California, Regional Wastewater Control Facility from rock media to plastic media and to develop general design considerations for similar conversions which might be carried out elsewhere.

The report reviews the history of wastewater treatment at Stockton and describes the planning studies which led to the selection of plastic media trickling filters for use at Stockton. Information on design of the secondary treatment modifications is presented, along with a description of plant construction and startup. Although other portions of the Stockton plant were upgraded at the time, this investigation centers on the secondary treatment process and considers other unit processes only as they relate to the trickling filter conversion.

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The Stockton plastic media trickling filters are designed to operate in two modes: (1) to oxidize carbonaceous material during the canning season when plant loadings are high (design flow = 220,000 m^3/day or 58 mgd) and (2) to provide combined carbon oxidation-nitrification during the noncanning season when loadings are low (design flow = 87,000 m^3/day or 23 mgd).

To evaluate plant performance, a special 1-yr sampling program was carried out. Analyses are presented for total and soluble BOD_5, total and soluble COD, total and volatile suspended solids, phosphorous, nitrogen forms (organic, ammonia, nitrate, and nitrite), alkalinity, pH, dissolved oxygen, and wastewater temperature. Sampling points were raw wastewater, primary effluent, unsettled trickling filter effluent, and secondary effluent (not all analyses were made for all sampling points).

Plant performance for the 1-yr period is presented and evaluated. Operational changes intended to improve performance are described, and the results are discussed. Capital and operating costs for filter conversion are also presented.

Based on information developed from evaluation of the Stockton plant and from review of other plastic media trickling filter plants, manufacturers' data, and technical literature, general design considerations are developed for converting

rock media trickling filters to plastic media, including both process design and physical design. Process design includes such performance parameters as BOD_5 removal, ammonia nitrogen removal (in combined and separate stage systems), suspended solids removal, and solids production. Physical design involves such considerations as wall design, influent and effluent piping, effluent collection, recirculation, and overall plant layout.

This report was submitted in fulfillment of Contract No. 68-03-2349 by Brown and Caldwell under the sponsorship of the U.S. Environmental Protection Agency. Plant operating and performance data are included in this report for the 1-yr period of March 15, 1976, through March 16, 1977.

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SECTION 1

INTRODUCTION

Rock media trickling filters have traditionally played an important role in U.S. wastewater treatment and are widely used in small and moderate-size communities. Their chief attributes are reliability, stability, ease of operation, and low operating costs. Their ability to remove contaminants is limited, however; at normal organic loadings (0.8 to 1.6 kg BOD_5 [5-day biochemical oxygen demand]/m^3/day or 50 to 100 lb/1,000 ft^3/day), BOD_5 and suspended solids removals of 60 to 85 percent are usually attained, with effluent concentrations generally ranging from 40 to 80 mg/l. At very low loadings (0.2 to 0.4 kg/m^3/day or 10 to 25 lb/1,000 ft^3/day), BOD_5 and suspended solids removals of over 85 percent can be realized, but except for all but the smallest plants, an excessive number of filters* and a very large land area are required.

Nitrification (conversion of ammonia nitrogen to the nitrate form) can also be attained at very low loadings and, in the past, has generally occurred incidental to oxidation of carbonaceous material. Nitrification has, however, become an important treatment process in recent years, either by itself for ammonia conversion or as an intermediate process in nitrogen removal.

An important recent innovation in trickling filtration technology has been the use of synthetic (plastic) media in place of rock. Although random-packed synthetic media can be obtained, the most common configuration involves interlocking plastic sheets constructed in modules which have a "honeycomb" appearance. These modules are then stacked to give a highly porous, clog-resistant trickling filter which can receive high hydraulic and organic loadings and produce a high quality effluent.

Recent emphasis on upgrading wastewater effluents discharged to surface waters has resulted in many trickling filter plants being unable to meet the more stringent discharge requirements which are now being imposed. Conversion from rock to plastic media may allow such plants to meet the new requirements and to receive increased flows and loadings. Plastic media trickling filters may be used alone in a conventional secondary treatment mode, or they may be integrated with other unit processes to provide advanced waste treatment capability.

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*In this report, the terms "trickling filter" and "biofilter" will be used synonymously; also, where the meaning is clear from the context, the shorter term "filter" will be used at times.

In 1969, the City of Stockton, California, was ordered by the California Regional Water Quality Control Board, Central Valley Region, to reduce the total nitrogen concentration in its wastewater effluent discharged to the San Joaquin River. Stockton is located in an agricultural area in central California, and its Regional Wastewater Control Facility (formerly called the Main Water Quality Control Plant) provides wastewater treatment for over 200,000 area residents and several industries including six major food processing plants which, during the canning season (July through October), cause the plant influent flow to triple and the organic loading to increase to five times the noncanning season average. In 1969, the plant flow diagram consisted of primary sedimentation, trickling filtration, and effluent polishing oxidation ponds. In order to meet the nitrogen limitation, a waste treatment scheme was developed which included the conversion of three of six existing rock media trickling filters to plastic media.

Other plant modifications were undertaken in conjunction with the trickling filter conversion; the most significant of these was construction of tertiary algae removal facilities consisting of dissolved air flotation, dual media filtration, and chlorination-dechlorination followed by stream discharge.

It was anticipated that the upgraded plant (Figure 1) would be operated in two modes. During the canning season, the plastic media trickling filters would remove carbonaceous oxygen demand from the high-strength wastes, effluent ammonia nitrogen would be incorporated into algae in the oxidation ponds, and the algae (and nitrogen) would be removed by dissolved air flotation-filtration. During the noncanning season when plant loadings are much lower, the plastic media filters would provide both the oxidation of carbonaceous material and nitrification. Nitrified effluent would then undergo denitrification (conversion of nitrate nitrogen to nitrogen gas) in the anaerobic bottom layer of the facultative oxidation ponds. During the transition period between canning and noncanning seasons, it was anticipated that conversion of ammonia nitrogen to nitrogen gas through breakpoint chlorination (followed by dechlorination) would be used to ensure compliance with the nitrogen limitation provision.

This report has been prepared to describe the conversion of the rock trickling filters at Stockton to plastic media filters, designed for removing carbonaceous BOD_5 during the canning season and capable of nitrifying during the noncanning season when low organic loadings are received at the plant. Although other plant components were upgraded or expanded during this same period, this report deals with them only as they relate to the secondary treatment portion of the facilities.

Figure 1. Stockton, California, Regional Wastewater Control Facility. Conversion from rock to plastic media trickling filters increased biological oxidation capacity and provided nitrification during noncanning season low loading conditions.

OBJECTIVES AND SCOPE

This review of the Stockton plant upgrading has been undertaken to make available information which may be useful to communities and engineering consultants who face situations where existing rock media trickling filters cannot meet new, more stringent discharge requirements.

Specific objectives were identified as follows:

1. Present information on conversion to the upgraded facility. This includes preliminary planning, detailed design, construction, and capital costs for the secondary treatment modifications.

2. Review operation and performance of the plastic media filters. Difficulties encountered in startup and operation are discussed, along with operational techniques developed to counter such problems. Because the rock and plastic media filters are normally operated in parallel with a common recirculation sump, a special 1-yr sampling and analysis program was undertaken to document performance. During this 1-yr period, the rock media filters were shut down to prevent interference with the plastic media filters. Data developed from the sampling program are presented, with particular attention given to comparing performance with design objectives. Operation and maintenance costs are also documented.

3. Develop general design considerations for converting rock trickling filters to plastic media. Experience gained from the Stockton plant is emphasized, but information from similar planned or constructed plants, from plastic media manufacturers, and from the technical literature is also utilized. Process design considerations include carbonaceous BOD_5 removal, nitrification performance, available media types, hydraulic loading, air requirements, interrelationship with secondary clarification, and solids production. Physical design considerations center principally on the use of existing structures for the upgraded plant and cover such items as use of existing filter structures, possible need for new influent and effluent lines, construction of new influent risers and distributors, supply and recirculation pumping, ventilation systems, and media installation.

OUTLINE OF REPORT

This report has been organized to present first a chronological history of the Stockton secondary treatment modifications and then to discuss specific aspects of plant operation and performance before setting out general design considerations. Sections 4 through 6, respectively, review the background, design, and construction and startup. Operation of the plastic media filters and the specific task of comparing performance with design objectives are covered in Section 7. Also included in Section 7 are capital and operating cost data for the Stockton secondary treatment facilities. Information from Sections 4 through 7 is then augmented by data from other sources for presentation in Section 8, General Design Considerations.

SECTION 2

CONCLUSIONS

Use of plastic media in the trickling filtration process has become widespread in the last 10 yr. This investigation of the Stockton Regional Wastewater Control Facility has provided valuable information for use in both the planning and design phases of treatment plant upgrading. Specific conclusions developed from this study are as follows:

- Conversion of rock media trickling filters to plastic media can be undertaken if the existing filter structures are structurally sound and if soil strength is adequate. Limitations on filter height or on wall type may result from necessary limits on allowable structure or soils loads.

- In conversion, significant modifications may need to be made to the following elements of the secondary treatment system: supply pumping, influent piping, rotary distribution, effluent collection, recirculation, and secondary clarification.

- Maintaining treatment during construction may limit design options; for example, a new recirculation structure may need to be built if the existing one cannot be shut down for required extensive modifications.

- The relation between the secondary treatment process and other plant unit processes, as well as the interrelationship among the secondary treatment components, should be carefully evaluated during design. Using existing structures usually limits design options, and considerable ingenuity may be required to provide overall plant flexibility and reliability.

- Module-type plastic media can be used in trickling filters to provide high BOD_5 removals. Effluent total and soluble BOD_5 concentrations measured at Stockton averaged less than 20 and 10 mg/l, respectively (removals averaged about 90 percent), at loadings of around 0.32 kg BOD_5/m^3/day (20 lb/1,000 ft^3/day) during optimal operation of the filters.

- Combined carbon oxidation-nitrification effluent ammonia nitrogen levels of less than 3.0 mg/l can be obtained in plastic media trickling filters (80 to 90 percent nitrification). Organic nitrogen removal is limited; removals of about 50 percent were measured at Stockton, with effluent concentrations ranging from 5 to 10 mg/l.

- Secondary effluent suspended solids concentrations at Stockton were above the 30 mg/l "secondary treatment" limit during 3 of 10 noncanning season months. Possible causes include poor hydraulic distribution among the four secondary clarifiers and within each clarifier; high secondary clarifier loading rates; and temperature/density gradients set up within the clarifiers by the forced draft ventilation system, which resulted in short-circuiting.

- The most commonly used design method for plastic media trickling filters is the Velz equation which, in one form, is as follows:

$$\frac{S_e}{S_o} = e^{-kA_v D/q^{0.5}} \qquad (1)$$

where: S_e = effluent BOD_5, mg/l

S_o = influent BOD_5, mg/l

k = treatability coefficient, dependent upon the wastewater

A_v = media specific surface area, ft^2/ft^3

D = media depth, ft

q = hydraulic loading (excluding recycle), gpm/ft^2.

While use of this equation is widespread, its applicability appears to be limited. Although the BOD_5 removal rate is generally improved by a higher media specific surface, the direct proportionality implied by the Velz equation does not appear to exist. Further, overall total BOD_5 removal, including secondary clarification, appears to be independent of depth for most applications.

- **Performance of the Stockton plant was limited during the first portion of the 1-yr sampling program by inadequate total hydraulic loading (influent plus recycle) capacity and/or inadequate air supply. After modification of these two operational parameters, performance (BOD_5 removal and nitrification) improved significantly.**

SECTION 3

RECOMMENDATIONS

Principal recommendations for future work involve the effect of secondary clarification on overall biofilter performance. Further investigation of the use of tube settlers and lower clarifier hydraulic loading rates to aid secondary clarification should be undertaken. Even though lower organic loadings (in terms of kg BOD_5/m^3/day or lb/1,000 ft^3/day) are being used to obtain higher BOD_5 removals, trickling filter clarifier overflow rates are still generally being designed near traditional values of around 40 $m^3/day/m^2$ (1,000 gpd/ft^2).

The possibility that temperature/density gradients can result from cooling of wastewater passing through the tower should be investigated. Particularly when combined carbon oxidation-nitrification is being practiced, high air flows and low influent hydraulic loading rates can result in a significant wastewater temperature drop through the biofilter. This in turn may result in density gradients within the secondary clarifier and consequent short-circuiting and deterioration in performance.

SECTION 4

BACKGROUND

Situated along the San Joaquin River in California's Central Valley, the City of Stockton is located 80 km (50 mi) east of San Francisco (Figure 2). Stockton is the county seat of San Joaquin County and its largest city. With a present population of approximately 200,000, Stockton is a major commercial center in the region. Because California's Central Valley is a rich agricultural area, principal industries in Stockton have long been those concerned with seasonal fruit and vegetable processing. Presently, there are six major food processing plants tributary to the Stockton plant. During the late summer months of August through October, these plants operate on an around-the-clock basis, discharging large quantities of wastewater to the Stockton sewerage system. Because the canning season coincides with the period of low flow in the San Joaquin River, the body of water to which Stockton's wastewater effluent is discharged, the canning season has always been a critical period for wastewater treatment at Stockton.

Topographically, the land surface in the Stockton area is a relatively flat plain which slopes in an east to west direction about 1 m/km (5 ft/mi). Principal geographical features of the area include the San Joaquin River, the Calavaras River, and various sloughs and channels which make up the eastern part of California's Sacramento-San Joaquin Delta area. River flow in Stockton is influenced by tidal action and by upstream diversions of water to state and federal water projects. These diversions may at times cause a net upstream water movement in the San Joaquin River at Stockton. Waste discharge requirements at Stockton have historically been developed to ensure adequate dissolved oxygen concentrations in the San Joaquin River and, more recently, to reduce algae growths in the river.

HISTORY OF WASTEWATER TREATMENT AT STOCKTON

Public sewerage in Stockton began prior to 1893 when existing sewers in the downtown area were connected to a large holding tank or cesspool located on the bank of Mormon Channel. Sewage was pumped from the tank through an outfall line to the San Joaquin River. Later, after failure of the line, raw sewage was discharged directly into Mormon Channel (1).

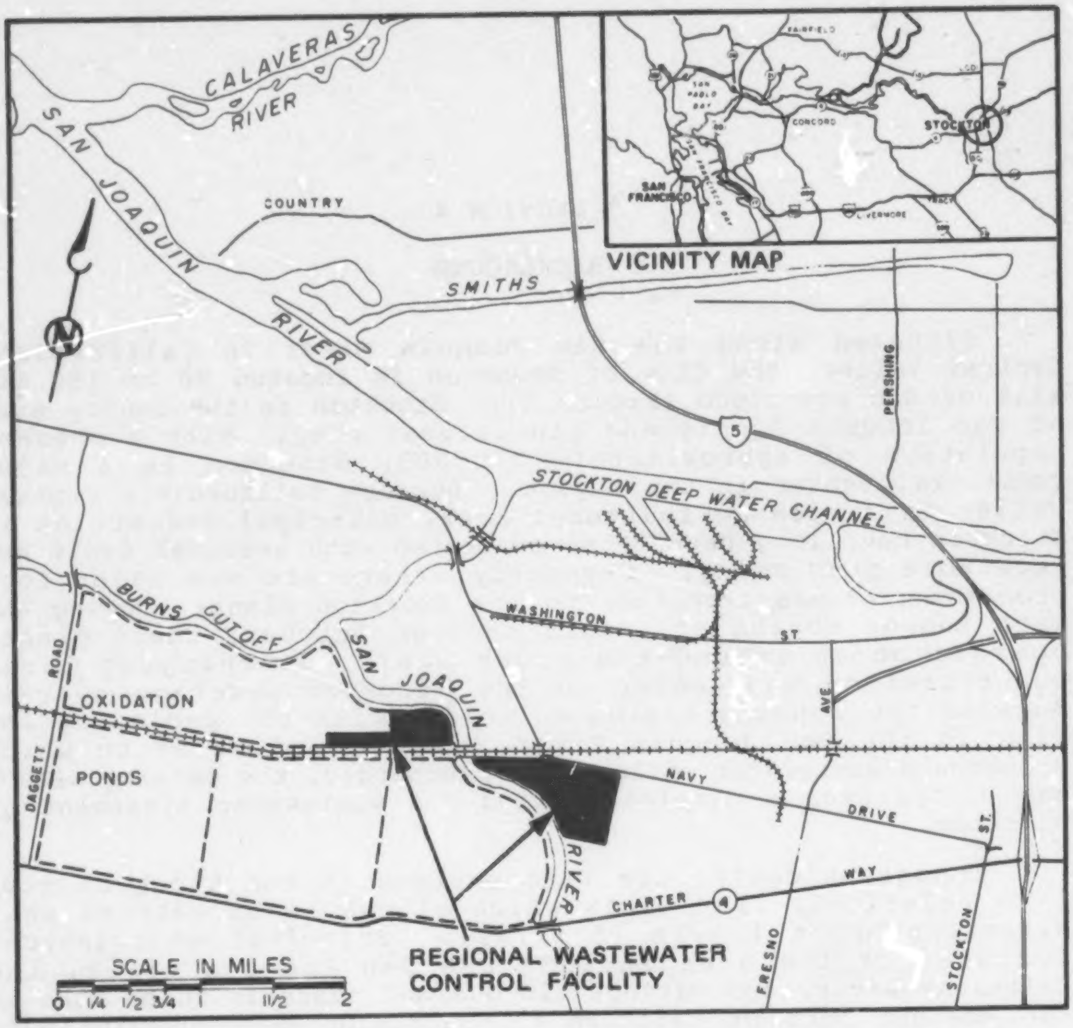


Figure 2. Location of Stockton plant.

Offensive odors and generally foul conditions resulting from this discharge led, in 1918, to the construction of a treatment plant on the north bank of Smith's Canal in what is now the downtown area. In 1922, following delay due to World War I, the south plant (now the Regional plant) was constructed adjacent to the San Joaquin River to serve that portion of the city located south of the Stockton ship channel. These plants provided only fine screening to accomplish the minimum amount of treatment.

By 1936, growth of the city had produced overloads on both plants, and had led to both unsightly and undesirable conditions in the receiving waters. At this time, primary sedimentation was provided at both locations.

Increased population and industrial growth brought about by World War II imposed excessive loadings on existing collection and treatment facilities. These conditions threatened to curtail sewer system expansion and industrial growth. The dissolved oxygen content of adjacent waters of the San Joaquin River and the Stockton ship channel was seasonally depressed below levels necessary to support fish life. In addition, the use of these waters for recreational purposes, including swimming and boating, presented a serious health menace. An engineering study undertaken in 1945 recommended provision of secondary treatment at both plants by construction of trickling filters and secondary sedimentation tanks. Secondary treatment was not provided at the Smith's Canal plant, however, and some of the wastewater previously flowing to that plant was, therefore, diverted to the Regional plant where basic structures for primary and secondary treatment were constructed.

Rapid development of the northern part of the city occurred after World War II, and in 1964, a new treatment plant, now identified as the north plant, was constructed to serve that area north of the Calaveras River. Meanwhile, it was found more economical to discontinue treatment at the Smith's Canal plant and to pump sewage from it to the Regional plant. Despite several increases in secondary treatment capacity, organic loadings from the Regional plant to the river exceeded its assimilative capacity during peak periods of food processing.

The Regional plant, as constituted up to the present expansion, had its inception from 1946 to 1948. Approximately \$3.0 million were spent for major reconstruction as part of a plan to divert all industrial wastes south, and to relieve the heavily overloaded treatment plant located on Smith's Canal. Units were constructed then to provide primary treatment and a portion of the recommended secondary treatment facilities comprising high-rate filters plus additional digester capacity to handle sludge from the Smith's Canal plant. Peak hydraulic capacity was 129,000 m^3/day (34 mgd). Between 1948 and 1961, construction projects involving nearly \$1.4 million were undertaken for additions, including primary and secondary sedimentation tanks, trickling filters, a sludge thickening unit, a chlorination facilities effluent pumping station, 81 ha (200 ac) of oxidation ponds, and an oxidation pond circulation and effluent pumping station. In 1963, work was authorized to increase hydraulic capacity throughout the plant and to provide an additional 55 ha (135 ac) of oxidation ponds and various other improvements necessary for efficient operation.

Hydraulic capacity, after completion of that work, was 193,000 m^3/day (51 mgd). In 1968 another 121 ha (300 ac) of oxidation ponds were added.

A flow diagram and the layout of the plant prior to the 1973-78 upgrading are shown in Figures 3 and 4, respectively. Design data for that plant are shown in Table 1. Performance of the plant for 1972 is summarized in Table 2.

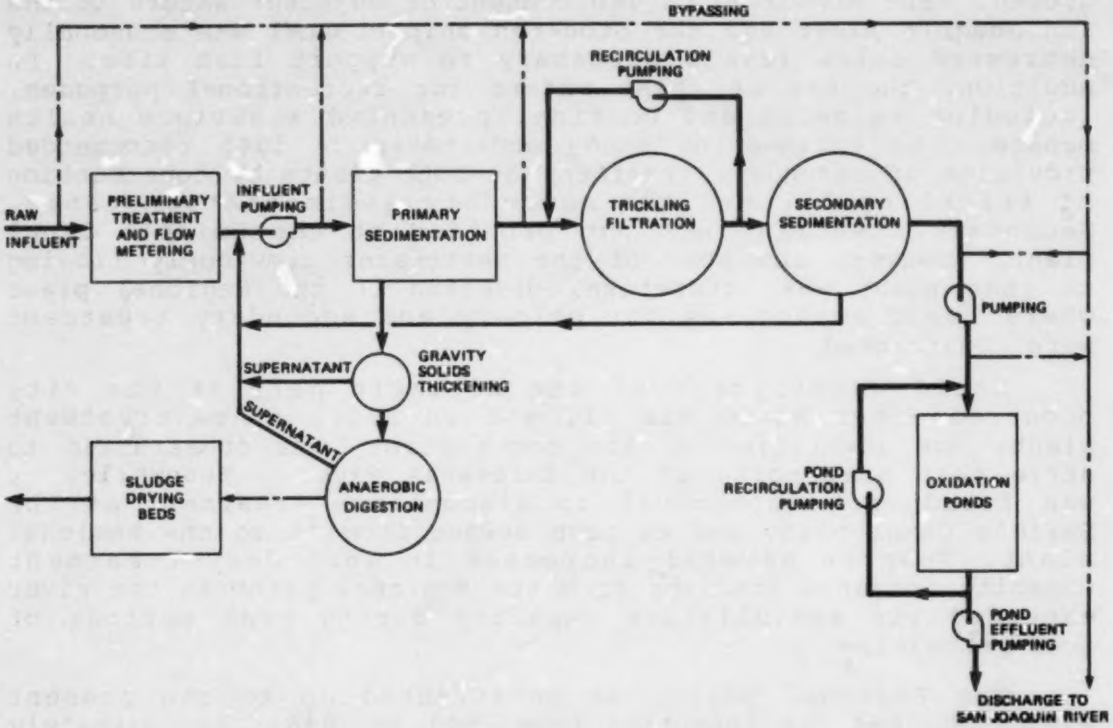


Figure 3. Flow diagram of Stockton plant prior to upgrading.

STOCKTON REGIONAL WASTEWATER CONTROL FACILITY

Groundwork for construction of the present facility was begun in February 1969 with the imposition of new discharge requirements by the Regional Water Quality Control Board (Appendix A). The most important provision of the previous requirements, issued in 1951, was that the dissolved oxygen concentration of the receiving water not fall below 3.0 mg/l. The new requirements raised the minimum allowable concentration to 5.0 mg/l. In addition, a receiving water total nitrogen limitation of 3.0 mg/l was imposed to reduce excessive algae growth as indicated in Section 1. A treatment scheme to meet the new regulatory requirements was developed by the city's consultants, Brown and Caldwell, and involved the use of plastic media trickling filters and a tertiary algae removal facility. The plant was designed to operate in two modes: during the canning season (approximately July through October) when the organic loading is high, the filters were to oxidize carbonaceous matter only with an expected BOD_5 removal of 70 percent. The various forms of nitrogen, primarily ammonia, were to be substantially removed by the oxidation pond through conversion to algae cells with subsequent algae removal in the tertiary facility (Figure 5). During the noncanning season when the organic loading is low, approximately 90 percent of the carbonaceous BOD_5 was to be removed in the trickling filters and ammonia nitrogen was to be converted to the nitrate form. The nitrate nitrogen formed in the filters was to be converted to nitrogen gas through microbial denitrification in the anerobic layer of the ponds. Based upon these requirements, design and construction of the facilities were undertaken.

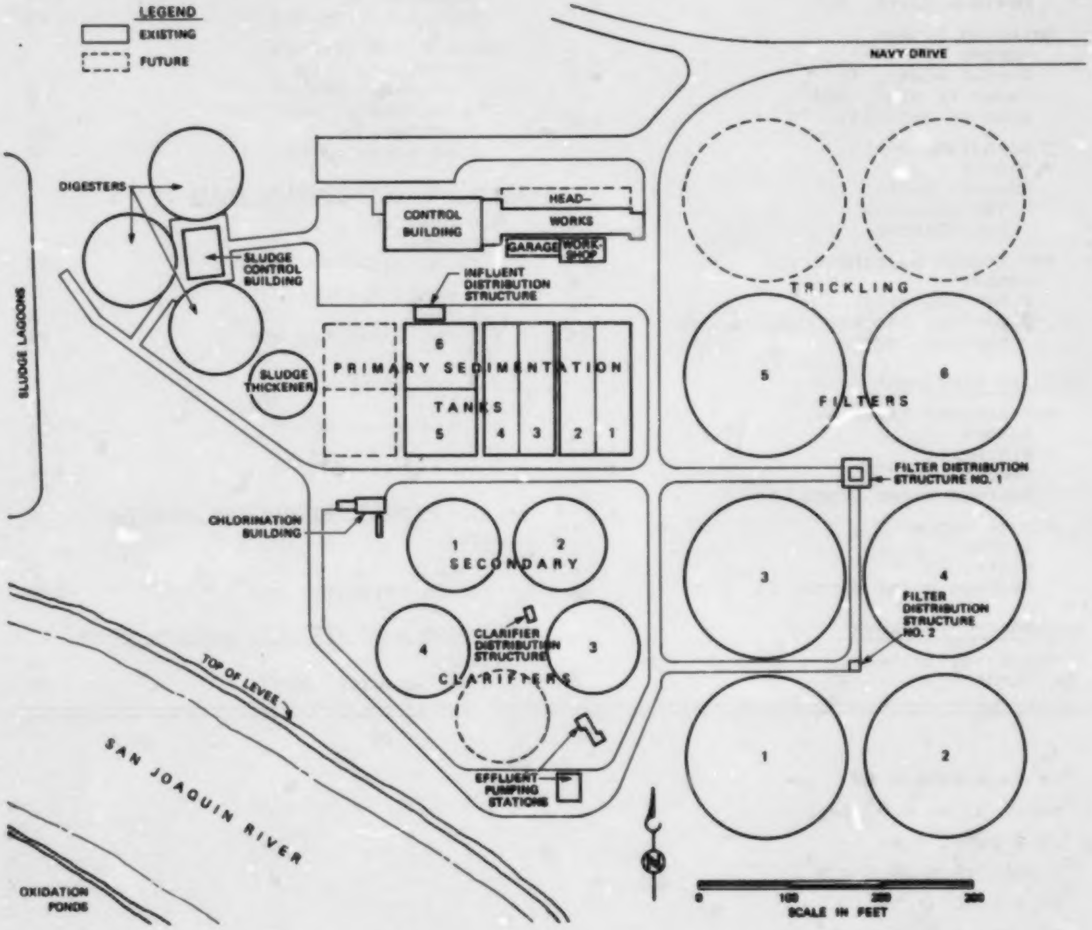


Figure 4. Plant layout prior to upgrading.

TABLE 1. DESIGN DATA, STOCKTON PLANT, PRIOR TO UPGRADING, 1964

Parameter	Value
Incoming sewers	
Diameter, in.[a]	
Number 1	30
Number 2	48
Number 3	48
Capacity without surcharge, mgd[b]	43
Preliminary treatment	
Bar screens	
Number	3
Width, ft[c]	4.0
Water depth, ft[c]	2.6
Grit removal channels	
Number	3
Width, ft[c]	4.0
Maximum depth, ft[c]	5.2
Metering flumes	
Number	3
Throat width, ft[c]	2.0
Capacity each, mgd[b]	17
Head at capacity, ft[c]	2.2
Comminuting units	
Number	3
Channel width, ft[c]	
Two channels	4.0
One channel	5.0
Raw sewage pumping units	
Number	4
Total capacity, mgd[b]	93
Capacity, largest pump not operating, mgd[b]	59
Primary treatment	
Rectangular tanks	
Number	4
Width, ft[c]	37
Length, ft[c]	141
Average water depth, ft[c]	15
Square tanks	
Number	2
Width, ft[c]	70
Average water depth, ft[c]	14
Secondary treatment	
Trickling filters	
Number	6
Diameter, ft[c]	166
Rock media depth, ft[c]	4.2
Total media volume, 1,000 ft^3[d]	540
Filter recirculation pumping units	
Number	4
Total capacity, mgd[b]	30
Secondary sedimentation tanks	
Number	4
Diameter, ft[c]	100
Side water depth, ft[c]	12
Solids treatment	
Gravity thickener	
Number	1
Diameter, ft[c]	70
Side water depth, ft[c]	10
Anaerobic digesters	
Number	
Primary, heated	2
Secondary, unheated	1
Diameter, ft[c]	100
Side water depth, ft[c]	30
Plant effluent pumping units	
Old station	
Number	2
Total capacity, mgd[b]	32
New station	
Number	2
Total capacity, mgd[b]	68
Oxidation ponds	
Number	2
Surface area, ac[e]	325
Depth, ft[c]	4.5
Volume, mil gal[f]	476
Oxidation pond circulation pumping units	
Number	2
Total capacity, mgd[b]	136
Oxidation pond effluent pumping units	
Number	4
Total capacity, mgd[b]	56

[a] in. x 0.0254 = m.

[b] mgd x 3,785 = m^3/day.

[c] ft x 0.305 = m.

[d] 1,000 ft^3 x 28.3 = m^3.

[e] ac x 0.405 = ha.

[f] mil gal x 3,785 = m^3.

TABLE 2. PERFORMANCE OF STOCKTON PLANT PRIOR TO UPGRADING, 1972

Parameter	Value	
	Canning season[a]	Noncanning season[b]
Flow, mgd[c]	32.2	16.4
BOD_5, mg/l		
Raw wastewater	380	240
Primary effluent	280	160
Secondary effluent	160	40
Pond effluent	33	15
Trickling filter organic loading, lb BOD_5/1,000 ft^3/day[d]	140	40
Secondary treatment BOD_5 removal, percent	43	75
Suspended solids, mg/l		
Raw wastewater	340	210
Primary effluent	77	61
Secondary effluent	49	48
Pond effluent	190	38
Pond effluent total nitrogen, mg/l	12.5	11.8

[a] Canning season; July - September.

[b] Noncanning season; October - June.

[c] mgd x 3,785 = m^3/day.

[d] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

In September 1974, before these facilities were completed, the Regional Water Quality Control Board again issued new requirements for the Stockton plant (Appendix B). Included in these requirements were monthly average effluent BOD_5 and suspended solids concentrations of 10 mg/l, and a monthly median total coliform organism concentration of 23 MPN/100 ml. In addition, a 3.0 mg/l limit on effluent total nitrogen was imposed, although this limitation only applied from the period of July 15 through November 15. The receiving water standards of 3.0 mg/l for total nitrogen and 5.0 mg/l for dissolved oxygen remained in effect.

If operated in two modes as planned, the plant could not have met these new discharge requirements. In January 1975, Brown and Caldwell analyzed the alternatives available for meeting the new requirements (2). It was concluded that the proposed facilities could produce effluent of the required quality through a change in operating modes. During the July 15 through November 15 period (which includes the canning season) when the 3.0-mg/l effluent nitrogen limitation is in effect, wastewater would be directed through all the unit processes: primary treatment, secondary treatment by trickling filtration, oxidation ponds, dissolved air flotation, dual media filtration, and chlorination-dechlorination. Outside the July 15 through November 15 period, during those periods when the river flow is high, the oxidation ponds and dissolved air flotation processes would be bypassed. Nitrified secondary effluent would be diverted to the dual media filtration and chlorination-dechlorination facilities prior to discharge. The 3.0-mg/l receiving water total nitrogen limitation would be met by dilution in the river.

In late 1979, the Regional Water Quality Control Board again modified the discharge requirements for Stockton (Appendix C). During the noncanning period from November 1 through July 31, 30-mg/l limits on monthly average BOD_5 and suspended solids concentrations apply; from August 1 through October 31, the limits for these two constituents are 10 mg/l as a monthly average. The monthly median coliform limitation is 23 MPN/100 md year-round, and the nitrogen limitation has been eliminated from the requirements.

The city is planning to operate the tertiary facility during the canning season when the more stringent requirements are in effect. During the noncanning season when the 30-mg/l BOD_5 and suspended solids limits apply, the city will operate the lightly loaded oxidation ponds in a series mode and bypass the tertiary facility.

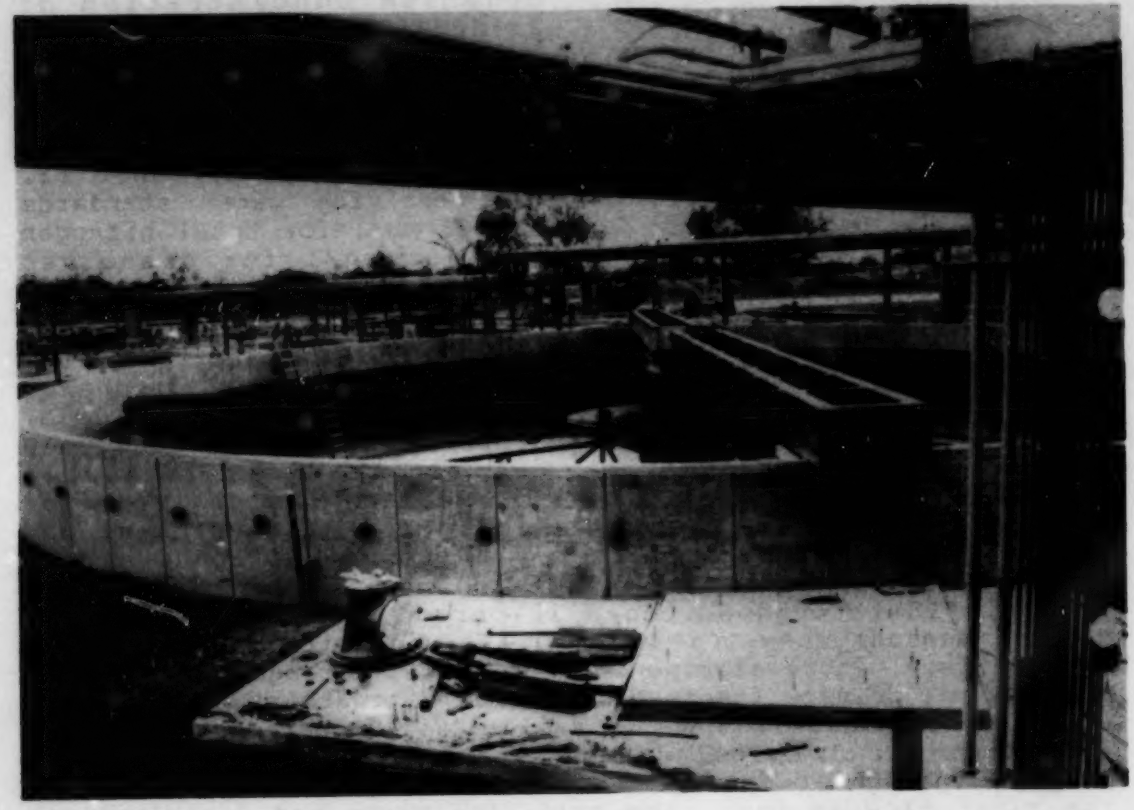


Figure 5. **Tertiary plant under construction. Dissolved air flotation will remove algae from oxidation pond effluent.**

It is believed that the 30-mg/l requirements can be met with oxidation pond effluent for a significant portion of the year, but all or a portion of the tertiary facility may be needed at times to meet these limits.

The flow diagram for the upgraded Stockton plant is shown in Figure 6. The layout (excluding the tertiary facilities) is shown in Figure 7. Plant design data are presented in Table 3.

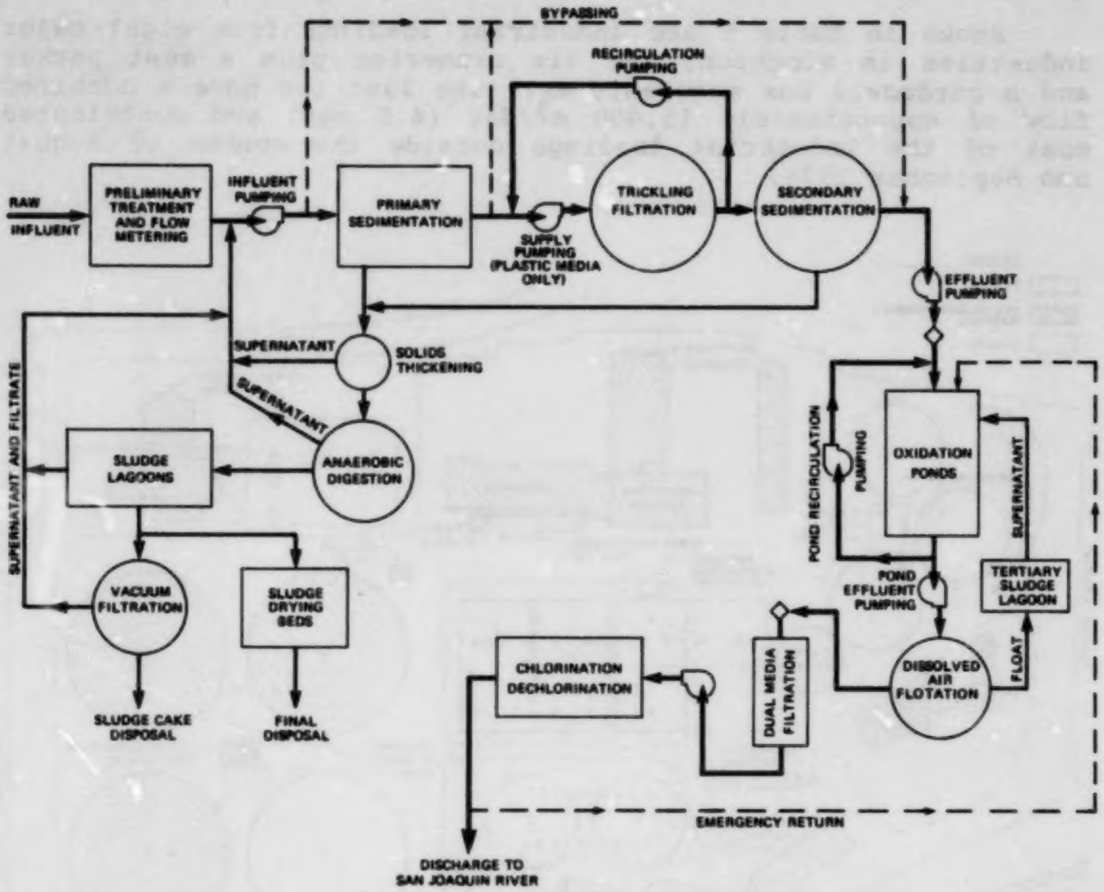


Figure 6. Flow diagram of upgraded plant.

WASTEWATER FLOWS AND CHARACTERISTICS

As previously mentioned, the occurrence of the fruit and vegetable canning season during the period of low river flow has historically been the critical period for wastewater treatment and discharge at Stockton. Shown in Figure 8 are weekly flows and BOD_5 loadings received at the plant during the period from March 15, 1976, through March 16, 1977, when the special sampling program was undertaken for this study.

The canning season began abruptly on August 1 when a cannery workers strike ended; normally, the canning season begins gradually in mid-July. The canning season also ended earlier than normal because of unusual late summer rains in September which resulted in considerable crop damage. Therefore, the canning season for 1976 was several weeks shorter than usual. Monthly plant influent characteristics are summarized in Table 4.

Shown in Table 5 are industrial loadings from eight major industries in Stockton, the six canneries plus a meat packer and a cardboard box manufacturer. The last two have a combined flow of approximately 15,000 m^3/day (4.0 mgd) and contributed most of the industrial loadings outside the months of August and September 1976.

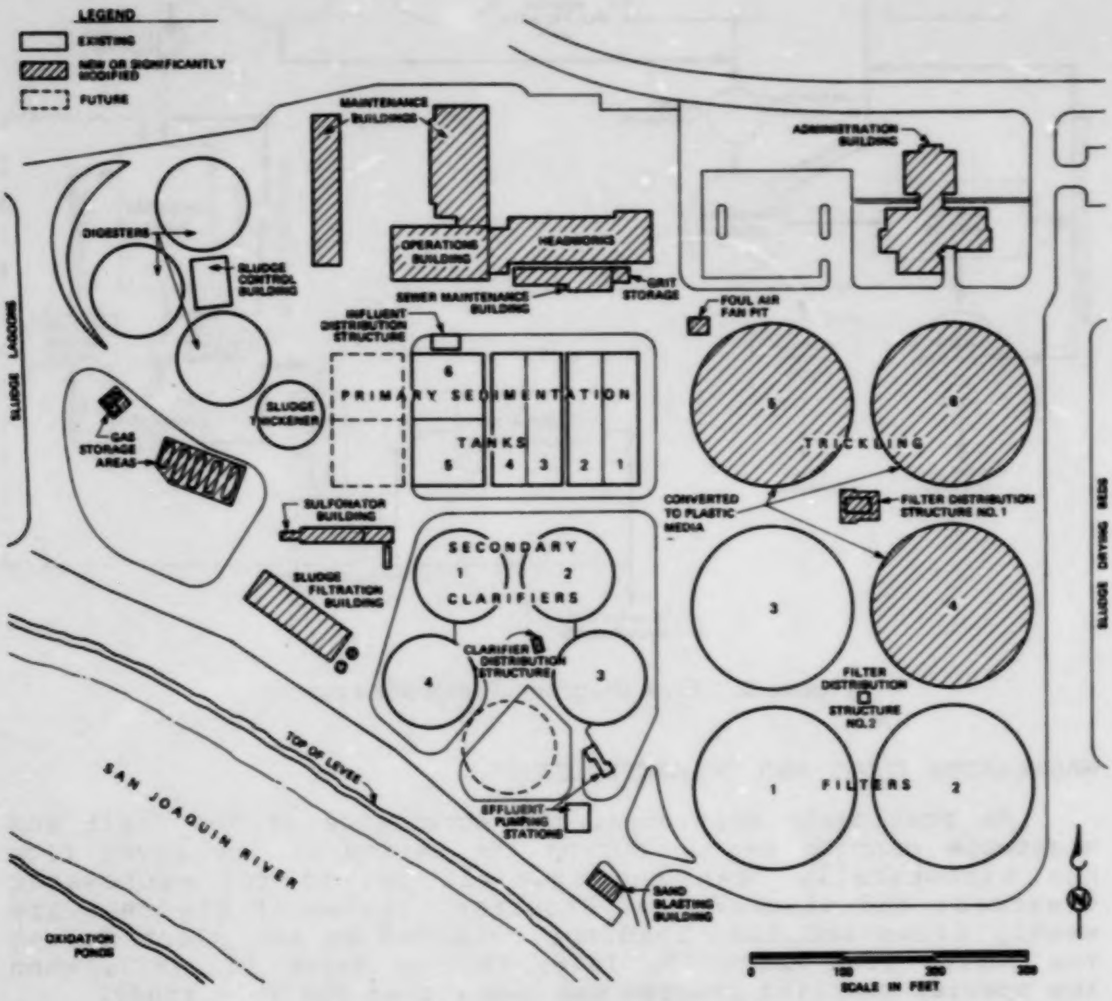


Figure 7. Plant layout after upgrading.

TABLE 3. DESIGN DATA FOR UPGRADED PLANT

Parameter	Value
Basic loading data	
Flow, mgd[a]	
Noncanning season	
Average dry weather (ADWF)	23
Peak storm rate	60
Canning season	
Maximum month	58
Peak rate	75
BOD$_5$, 1,000 lb/day[b]	
Noncanning season	54
Canning season, maximum month	236
Suspended solids, 1,000 lb/day[b]	
Noncanning season	31
Canning season, maximum month	167
Preliminary treatment	
Bar screens	
Number	3
Width, ft[c]	4.0
Water depth, ft[c]	2.9
Grit channels	
Number	6
Width, ft[c]	4.0
Maximum depth, ft[c]	5.4
Metering flumes	
Number	6
Throat width, ft[c]	2.0
Hydraulic capacity, each, mgd	20
Raw sewage pumping units	
Number	4
Capacity, each, mgd[a]	34(3) 14.5(1)
Primary treatment	
Sedimentation tanks	
Rectangular tanks	
Number	4
Width, ft[c]	37
Length, ft[c]	141
Average water depth, ft[c]	15
Weir length, each, ft[c]	224
Square tanks	
Number	2
Width, length, ft[c]	70
Average water depth, ft[c]	14
Weir length, each, ft[c]	260
Detention time, hours	
ADWF noncanning season	3.4
Maximum day canning season	1.2
Overflow rate, gpd/ft^2[d]	
ADWF noncanning season	800
Maximum day canning season	2,200
Performance during noncanning season	
BOD$_5$ removal, percent	40
Suspended solids removal, percent	65
Performance during canning season	
BOD$_5$ removal, percent	20
Suspended solids removal, percent	55
Secondary treatment	
Trickling filters	
Trickling filters (rock)	
Number	3
Diameter, ft[c]	166
Average depth of media, ft[c]	4.2
Volume of media, each, 1,000 ft^3[e]	90
Total volume of media, rock filters, 1,000 ft^3[e]	270
Hydraulic capacity, each, mgd	10
Trickling filters (plastic)	
Number	3
Diameter, ft[c]	166
Average depth of media, ft[c]	22
Volume of media, each filter, 1,000 ft^3[e]	476
Total volume of media, plastic filters, 1,000 ft^3[e]	1,430
Hydraulic capacity, each filter, mgd[a]	24
Total volume of media, rock and plastic filters, 1,000 ft^3[e]	1,700
Loading, noncanning season	
BOD$_5$, lb/1,000 ft^3/day[f]	19
BOD$_5$ removal, percent	90
Recirculation ratio	3.4
Loading, canning season	
BOD$_5$, lb/1,000ft^3/day[f]	110
BOD$_5$ removal, percent	70
Recirculation ratio	0.76
Sedimentation tanks	
Number	4
Diameter, ft[c]	100
Side water depth, ft[c]	12
Overflow rate, gpd/ft^2[d]	
ADWF noncanning season	730
Peak storm rate	1,910
Maximum month canning season	1,850
Peak rate canning season	2,390
Suspended solids in effluent, mg/l	
Noncanning season	35
Canning season	165
Secondary effluent pumping units	
Number	3
Capacity, all pumps operating, mgd[a]	120
Capacity, largest unit out of service, mgd[a]	90
Solids treatment	
Gravity thickener	
Number	1
Diameter, ft[c]	70
Side water depth, ft[c]	10
Primary digestion tanks	
Number	3
Inside diameter, ft[c]	100
Side water depth, ft[c]	30

(continued on next page)

TABLE 3. (continued)

Parameter	Value
Solids treatment (con't)	
Primary digestion tanks (con't)	
Loading, lb/ft^3/day[g]	
Noncanning season	0.04
Canning season	0.25
Performance, noncanning season	
Suspended solids reduction, percent	55
Digested sludge, 1,000 lb/day[b]	12
Gas produced, ft^3/lb suspended solids/day[h]	6.0
Performance, canning season	
Suspended solids reduction, percent	45
Digested sludge, 1,000 lb/day[b]	95
Gas produced, ft^3/lb suspended solids/day[h]	5.5
Secondary sludge lagoons	
Number	2
Total area, ac[i]	3.8
Average liquid depth, ft[c]	6
Digested sludge solids content from digester, percent	3
Detention time in lagoon, days	59
Solids reduction in lagoon, percent	20
Vacuum filters	
Number	2
Capacity, each, lb suspended solids/hr[j]	1,200
Moisture content of wet cake, percent	60
Oxidation ponds	
Number	4
Area, net water surface, ac[i]	630
Volume, mil gal[k]	1,320
Loading, noncanning season	
BOD_5 lb/surface ac/day[l]	5
BOD_5 in effluent, mg/l	15
Suspended solids in effluent, mg/l	35
Loading, canning season	
BOD_5 lb/surface ac/day[l]	90
BOD_5 in effluent, mg/l	35
Suspended solids in effluent, mg/l	170
Circulation pumping units	
Number	3
Capacity, each, mgd[a]	65
Circulation ratio	3.4
Tertiary treatment	
Loadings	
Flow, mgd[a]	55
Suspended solids	
Concentration, mg/l	170
Loading, 1,000 lb/day[b]	78
Ammonia nitrogen, peak	
Concentration, mg/l	6.5
Loading, lb/day[j]	3,000
Tertiary treatment (con't)	
Chemical treatment	
Alum, peak rates	
Dry dosage, mg/l (17 percent Al_2O)	250
Volume, 1,000 gal/day[m] (8.3 percent Al_2O_3)	21.2
Sulfuric acid, peak rate, (93 percent H_2SO_4)	
Dosage, meq/l	3.0
Volume, gal/day[m]	4,700
Polyelectrolyte, peak rate, (0.5 percent solution)	
Dosage, mg/l	2.0
Volume, gpm[n]	15.0
Chlorine, peak capacities	
Prechlorination,	
mg/l	17.5
1,000 lb/day[b]	8
Filter influent,	
mg/l	17.5
1,000 lb/day[b]	8
Disinfection,	
mg/l	5
1,000 lb/day[b]	2.3
Ammonia nitrogen removal,	
mg/l	105
1,000 lb/day[b]	48
Dechlorination	
Sulfuric dioxide, peak rate,	
mg/l	8.3
1,000 lb/day[b]	3.8
Raw water pumps	
Number	4
Capacity, each, mgd[a]	13.75
Total head, each, ft[c]	11.0
Flotation tanks	
Number	4
Diameter, each, ft[c]	85
Side water depth, ft[c]	7
Solids loading rate, lb/ft^2/day[o]	5.1
Assumed float concentration, percent	3
Peak float discharge rate, gpm[n]	600
Surface loading rate, including pressurized flow, gpm/ft^2[p]	2.4
Pressurized flow, gpm[n]	4,500
Pressure, maximum psig[q]	80
Air flow, maximum scfm[r]	80
Air to solids ratio, minimum, kg air/kg solids	0.179
Dual medial filters	
Number (bifurcated)	4
Width, ft[c]	34
Length, ft[c]	50
Filtration rate, gpm/ft^2[p]	
All filters in service	5.7
One in backwash	7.5

(continued on next page)

TABLE 3. (continued)

Parameter	Value
Tertiary treatment (con't)	
Dual medial filters (con't)	
Media	
Anthracite coal	
Depth, ft[c]	4
Effective size, mm	1.0-1.1
Sand	
Depth, ft[c]	1.5
Effective size, mm	0.65-0.75
Gravel	
Depth, ft[c]	0.67
Backwash	
Air	
Rate, cfm/ft^2 [s]	4
Volume, cfm[r]	3,400
Water	
Rate, gpm/ft^2 [p]	
Minimum	13
Maximum	26
Volume, mgd[a]	
Minimum	16.0
Maximum	32.0
Tertiary treatment (cont'd)	
Filtered water pumping station	
Number of pumps	3
Capacity, each, mgd[a]	21.5
Total head, ft[c]	15.7
Chlorine contact canal	
Length, ft[c]	1,030
Average width, ft[c]	19.26
Depth, ft[c]	7.63
Detention time, min	30
Reaeration blowers	
Number	2
Capacity, each, cfm[r]	1,500

[a] mgd x 3,785 = m^3/day.

[b] 1,000 lb/day x 0.454 = 1,000 kg/day.

[c] ft x 0.305 = m.

[d] gpd/ft^2 x 0.0407 = m^3/day/m^2.

[e] 1,000 ft^3 x 0.0283 = 1,000 m^3.

[f] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

[g] lb/ft^3/day x 16 = kg/m^3/day.

[h] ft^3/lb/day x 0.062 = m^3/kg/day.

[i] ac x 0.405 = ha.

[j] lb x 0.454 = kg.

[k] mil gal x 3,785 = m^3.

[l] lb/ac/day x 1.12 = kg/ha/day.

[m] gal/day x 3.78 = l/day.

[n] gpm x 0.063 = l/sec.

[o] lb/ft^2/day x 4.88 = kg/m^2/day.

[p] gpm/ft^2 x 0.0407 = m^3/min/m^2.

[q] psig x 6.89 = kN/m^2.

[r] scfm x 0.0283 = std. m^3/min.

[s] cfm/ft^2 x 0.305 = m^3/min/m^2.

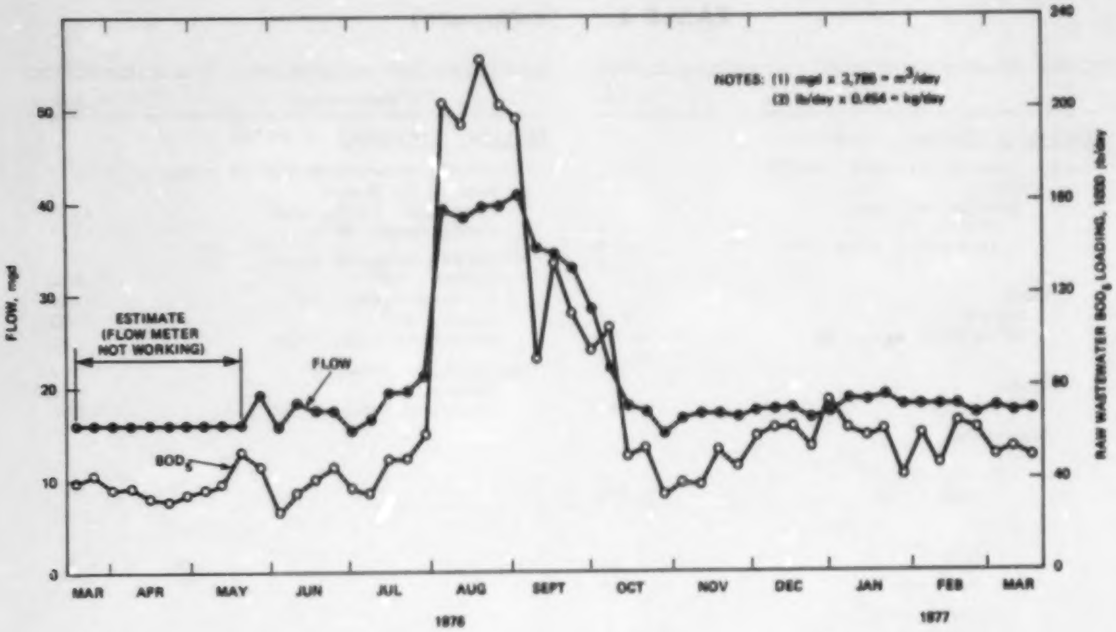


Figure 8. Plant flow and BOD_5 loadings for period of special sampling program.

TABLE 4. WASTEWATER FLOWS AND CHARACTERISTICS

Parameter	Value	
	Canning season[a]	Noncanning season[b]
Flow, mgd[c]	37	17
BOD_5, mg/l	530	320
BOD_5, 1,000 lb/day[d]	160	45
Suspended solids, mg/l	660	380
Suspended solids, 1,000 lb/day[d]	200	54
COD, mg/l	970	670
COD, 1,000 lb/day[d]	300	95
Ammonia nitrogen, mg/l	12	20
Organic nitrogen, mg/l	17	15
Total phosphorus, mg/l	6.1	8.6

[a] August 1 - September 30, 1976.

[b] March 15 - July 31, 1976; November 1, 1976 - March 16, 1977.

[c] mgd x 3,785 = m^3/day.

[d] 1,000 lb/day x 0.454 = 1,000 kg/day.

TABLE 5. INDUSTRIAL WASTE LOADINGS FOR THE STOCKTON PLANT

Parameter	Value[a]	
	Canning season[b]	Noncanning season[c]
Flow, mgd[d]	22	3.8
BOD_5, mg/l	670	580
BOD_5, 1,000 lb/day[e]	120	18
Suspended solids, mg/l	550	450
Suspended solids, 1,000 lb/day[e]	100	14

[a] Represents six canneries, one meat packer, and one cardboard box manufacturer.

[b] August - September 1976.

[c] March - July 1976; November 1976 - February 1977.

[d] mgd x 3,785 = m^3/day.

[e] 1,000 lb/day x 0.454 = 1,000 kg/day.

SECTION 5

DESIGN

Imposition of the February 1969 Regional Water Quality Control Board requirement calling for a reduction of nitrogen in the Stockton plant effluent necessitated development of a scheme for removal of nitrogen during both the canning and noncanning seasons. This previously described scheme involved algae removal during the canning season and nitrification-denitrification during the noncanning season.

Initially, the city's consultants recommended in a 1969 report that the activated sludge process be added to the plant flow diagram and that it be operated in parallel with the existing rock trickling filters (3). The algae removal process recommended for use was coagulation-flocculation-sedimentation to be followed by filtration and disinfection prior to stream discharge.

Investigation into alternative processes following the 1969 recommendations eventually resulted in two major changes in the recommended plan. Plastic media trickling filtration, then coming into widespread use, was substituted for the parallel activated sludge/rock trickling filter processes. Dissolved air flotation was substituted for coagulation-flocculation-sedimentation as the algae removal process.

Use of plastic media trickling filtration had two major advantages over the dual process plan previously considered. First, conversion of the existing rock media biofilters to plastic media was significantly less costly than addition of separate aeration tanks and activated sludge secondary clarifiers. Second, operating the two processes in parallel would have resulted in needless operational complexities; the situation would have been equivalent to operating two separate plants with twice the probability for upsets and problems. Since plastic media trickling filtration was a relatively new process, however, there was some doubt concerning the expected performance of the filters, particularly with regard to nitrification. To ensure that the recommended biofilters could perform as planned, a 5-mo pilot study was carried out during the summer of 1972. Results of that study will be described briefly below.

Design of the secondary treatment modifications at Stockton can be conveniently divided into two aspects: process design and physical design. While these aspects cannot be totally divorced from each other, the differentiation is useful in presenting an organized discussion of the Stockton upgrading. Process design includes the interrelationships among projected influent loadings, required effluent characteristics, anticipated removals in each unit process, and sizing of added unit processes. Physical design includes such factors as general site layout, structural design of the biofilters and associated structures, mechanical equipment specifications, site piping, and operational flexibility.

A description of the entire plant, including primary, secondary, and tertiary treatment facilities and solids handling and treatment processes, was presented in Section 4. Information in this section will concern the secondary treatment portion of the plant. A summary of design data for the secondary treatment facilities is presented in Table 6.

PROCESS DESIGN

In contrast to the relatively sophisticated design approaches which have been developed for the activated sludge process, trickling filtration design has remained essentially empirical in nature. A method often used for design of plastic media biofilters involves use of the Velz equation:

$$\frac{S_e}{S_o} = e^{-k_1 D/q^{0.5}} \tag{1a}$$

where:

S_e = effluent BOD_5, mg/l

S_o = influent BOD_5, mg/l

k_1 = treatability coefficient

D = media depth, ft

q = hydraulic loading, (excluding recycle) gpm/ft^2.

The treatability coefficient, k, depends on the type of waste being treated. For domestic wastewater, values of 0.07 to 0.08 are usually cited. For industrial wastes, lower values of k are often found. Industrial waste treatability varies more than domestic waste, but typically cited values of k range from 0.04 to 0.055. (Equation 1a differs slightly from Equation 1 in that the media specific surface is hidden in the treatability coefficient, k.)

TABLE 6. DESIGN DATA SUMMARY FOR SECONDARY TREATMENT FACILITIES

Parameter	Value
Flow, mgd[a]	
Noncanning season	
Average dry weather	23
Peak storm rate	60
Canning season, peak month	58
Loadings	
BOD_5, mg/l	
Noncanning season	170
Canning season, peak month	390
BOD_5, 1,000 lb/day[b]	
Noncanning season	32
Canning season, maximum month	189
Suspended solids, mg/l	
Noncanning season	60
Canning season, peak month	155
Suspended solids, 1,000 lb/day[b]	
Noncanning season	11
Canning season, peak month	75
Trickling filters	
Rock media trickling filters	
Number	3
Diameter, ft[c]	166
Media depth, ft[c]	4.2
Total volume, 1,000 ft^3[d]	270
Total hydraulic capacity (including recirculation), mgd[a]	30
Plastic media trickling filters	
Number	3
Diameter, ft[c]	166
Media depth, ft[c]	22
Total volume, 1,000 ft^3[d]	1,430
Total hydraulic capacity (including recirculation), mgd[a]	72
Unit loading, lb $\text{BOD}_5/1{,}000\ \text{ft}^3/\text{day}$[e]	
Noncanning season	19
Canning season, peak month	110
Recirculation	
Recirculation pump capacity, mgd[a]	76
Recirculation ratio (recycle/influent)	
Noncanning season	3.4
Canning season, peak month	0.76
Secondary sedimentation tanks	
Number	4
Diameter, ft[c]	100
Side water depth, ft[c]	12
Detention time, hr	
Noncanning season	2.9
Canning season, maximum month	1.2
Overflow rate, gpd/ft^2[f]	
Noncanning season, ADWF	700
Peak storm rate	1,900
Canning season, maximum month	1,800
Secondary treatment performance	
Noncanning season	
BOD_5 removal, percent	90
Effluent BOD_5, mg/l	17
Effluent suspended solids, mg/l	35
Canning season, maximum month	
BOD_5 removal, percent	70
Effluent BOD_5, mg/l	120
Effluent suspended solids, mg/l	165

[a] mgd x 3,785 = m^3/day.

[b] 1,000 lb/day x 0.454 = 1,000 kg/day.

[c] ft x 0.305 = m.

[d] 1,000 ft^3 x 28.3 = m^3.

[e] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

[f] gpd/ft^2 x 0.0407 = $\text{m}^3/\text{day}/\text{m}^2$.

Modifications to the Stockton trickling filters involved conversion of three of the existing rock media biofilters to plastic media and retaining the three remaining rock media biofilters. Loadings and recirculation rates given in Tables 3 and 6 are based upon this configuration. This was a slight modification to an earlier plan involving two plastic media filters (6.7 m or 22 ft deep) and four redwood media filters (1.3 m or 4.25 ft deep). Canning season organic loadings, normally critical for design, were 2.2 kg BOD_5/m^3/day (135 lb/1,000 ft^3/day) for two plastic and four redwood media filters and 1.8 kg/m^3/day (110 lb/1,000 ft^3/day) for three plastic and three rock biofilters. Noncanning season loadings were 0.37 kg BOD_5/m^3/day (23 lb/1,000 ft^3/ day) for two plastic and four redwood filters and 0.30 kg/m^3/day (19 lb/1,000 ft^3/ day) for three rock and three plastic media filters. Estimated removals were 70 percent for the canning season and 90 percent for the noncanning season. Although cross-connections between the rock and plastic filters makes it difficult to relate these removals to their respective loadings using the Velz equation, evaluations of k for plastic media alone will be presented in Section 7 for the pilot study and for the Stockton plant during the special 1-yr sampling program undertaken in conjunction with this study.

Hydraulic Loadings

The maximum hydraulic loading for the plastic media filters is 0.031 $m^3/min/m^2$ (0.77 gpm/ft^2) at the design application rate of 91,000 m^3/day (24 mgd) per filter. At this loading, the recirculation ratio during the canning season maximum month is 0.76:1; during the noncanning season, it is 3.4:1.

Because the speed of the trickling filter supply pumps can be varied, the hydraulic loading can be decreased below the maximum value cited above. A lower hydraulic loading, approximately 0.024 $m^3/min/m^2$ (0.6 gpm/ft^2), was being applied to the plastic media biofilters during the first portion of the sampling program carried out for this study. Because this loading was lower than that recommended by the media manufacturer for complete "wetting" of the media surface, the pump speed was increased during the last portion of the sampling program in an attempt to improve performance. The results of that operational change are presented in Section 7.

Nitrification

There was little information available at the time concerning nitrification (conversion of ammonia nitrogen to the nitrate form) in trickling filters, particularly with plastic media. The most extensive study had been done by the National Research Council during World War II (4). That study indicated that a high degree of nitrification could be obtained in rock media trickling filters at organic loadings below approximately 0.19 kg BOD_5/m^3/day (12 lb/1,000 ft^3/day). The specific surface of plastic media is much greater than for rock media, 82 to 132 m^2/m^3 (25 to 40 ft^2/ft^3) for plastic compared with 39 to 59 m^2/m^3 (12 to 18 ft^2/ft^3) for 8-cm (3-in.) rock. It is, therefore, reasonable to expect that nitrification can be obtained with higher loadings when using plastic media. The combined noncanning-season, design average loading of 0.30 kg BOD_5/m^3/day (19 lb/1,000 ft^3/day) for the plastic plus rock filters was judged to be sufficiently low to expect a high degree of nitrification.

Air Supply

Air containing oxygen to allow bacterial growth is supplied to each plastic media biofilter by eight fans. The design air flow with all fans operating is 1.8 $m^3/min/m^2$ (6.0 cfm/ft^2), which is equivalent to an oxygen supply of approximately 1,270,000 kg oxygen/day (2,800,000 lb/day) to each of the three filters.

Generally, it is estimated that 2 to 5 percent of the oxygen that passes through a biofilter is available for use by microorganisms. The maximum-day design BOD_5 loading to the filters is 111,000 kg/day (245,000 lb/day). Assuming that the oxygen required is equal to the BOD_5 loading, the peak rate of oxygen required is approximately 3 percent of the maximum supply rate.

Forced draft ventilation was chosen for use because of the high canning season loads received at Stockton. The question of whether natural ventilation is adequate or whether forced draft ventilation is necessary will be discussed in Section 8.

Specific Surface Area

Contract documents prepared for the Stockton project did not specify a minimum specific surface area. The two plastic media manufacturers represented in the bidding (see Section 6) were Dow Chemical Co. and B. F. Goodrich; both offered media with a specific surface area of 89 m^2/m^3 (27 ft^2/ft^3). The contractor representing B. F. Goodrich was the low bidder and was selected for the job (see Section 6).

Pilot Study

Because the design loadings for the Stockton plant were unique and because of the relative absence of data regarding nitrification performance of plastic media biofilters, a 5-mo pilot study was conducted from mid-July through mid-December, 1972 (5,6). A further purpose of the study was to determine whether odors might be produced by the tower during high loading periods. Previous odor problems from plastic media biofilters used for combined domestic and cannery wastes in a nearby city were the principal cause for this concern. A brief description of the pilot study and its results is presented below. A more complete discussion has been published elsewhere (6).

Description of Pilot Plant and Procedures--

The pilot plant used for the study consisted of a steel shell 0.9 m (3 ft) in diameter and approximately 9.1 m (30 ft) high which contained a total of 4.2 m^3 (150 ft^3) of Surfpac plastic media (6.55 m or 21.5 ft high and 0.65 m^2 or 7 ft^2 cross-sectional area). The specific surface for Surfpac (manufactured at that time by Dow Chemical Co. and now manufactured by Envirotech) is 89 m^2/m^3 (27 ft^2/ft^3). Loadings applied to the pilot plant (with the exception of two particular periods) were varied to simulate loadings which would have been received by the full-scale plant had it been in operation in 1972. The study was timed to obtain data from the canning season, a portion of the noncanning season, and the transition period from canning to noncanning loadings when nitrification would be initiated within the biofilter.

During two portions of the study, once in the canning season and once in the noncanning season, the loadings were increased. This allowed performance of the filter to be evaluated under design loading conditions.

Forced air flow through the tower at the design rate of 1.8 $m^3/min/m^2$ (6 cfm/ft^2) was provided by a small fan. Supplemental nitrogen was added to the nutrient-deficient cannery waste during the canning season; diammonium phosphate was added to the influent at a sufficient rate to provide 1 kg nitrogen/20 kg BOD_5 removed.

Twenty-four-hr composite samples of influent (Stockton plant primary effluent) and effluent streams were taken three times per week from July 17, 1972, through December 13, 1972. Pilot plant effluent samples were settled 60 min in an Imhoff cone prior to analysis to simulate secondary clarification. Analyses were made for BOD_5, soluble BOD_5, COD, suspended solids, nitrogen forms, alkalinity, and pH.

During the latter part of the study, high effluent BOD_5 values led to the belief that nitrification was occurring in the BOD_5 bottle. Normally, nitrification in the BOD test takes 15 to 20 days to occur; values obtained in the standard 5-day test period then represent carbonaceous BOD only. However, when BOD_5 analyses are undertaken on well-stabilized effluents containing high populations of nitrifying organisms and ammonia nitrogen for substrate, it is possible for nitrification to occur within the 5-day incubation period.

In order to prevent this from occurring, BOD_5 tests for the last portion of the study were run using a 0.1-M ammonium chloride solution to suppress nitrification (7). Ammonia nitrogen in such excessively high concentration is toxic to the nitrifying organisms.

At the time the pilot study was undertaken, it was believed that while the 0.1-M ammonium chloride solution would preclude nitrification in the BOD_5 test, carbonaceous BOD_5 would not be affected. Information developed since that time, however, now indictes that carbonaceous BOD may in fact be reduced by the addition of ammonium chloride. This question is discussed further in Appendix D.

Pilot Study Results--

Results of the 1972 pilot study are summarized in Table 7 for two periods: the canning season (July 17 through September 15, 1972) and the noncanning season (October 16 through December 13, 1972). The transition period from September 16 through October 15 was omitted from the table. For the noncanning season, effluent BOD$_5$ values are shown with and without suppression of nitrification.

TABLE 7. PILOT STUDY RESULTS

Parameter	Canning season[a]			Noncanning season[b]		
	Influent[c]	Effluent[d]	Removal, percent	Influent[c]	Effluent[d]	Removal, percent
Main plant flow, mgd[e]	36	-	-	15	-	-
Temperature, C	29	-	-	26	-	-
BOD$_5$, mg/l						
With nitrogen suppression[f]	-	-	-	140	10	93
Without nitrogen suppression	310	71	77	150	21	86
Soluble BOD$_5$, mg/l						
With nitrogen suppression[f]	-	-	-	120	16	86
Without nitrogen suppression	280	37	87	120	18	84
COD, mg/l	550	220	60	340	97	72
Total suspended solids, mg/l	110	42	62	70	27	61
Organic nitrogen, mg/l	15	11	27	12	8.9	26
Ammonia nitrogen, mg/l	3.5[g]	18[g]	-	16	1.4	91
Alkalinity, mg/l as CaCO$_3$	240	310	-	170	110	-
pH	6.9	7.7	-	7.0	7.7	-

[a] July 17, 1972 to September 15, 1972.

[b] October 16, 1972 to December 13, 1972.

[c] Stockton plant primary effluent.

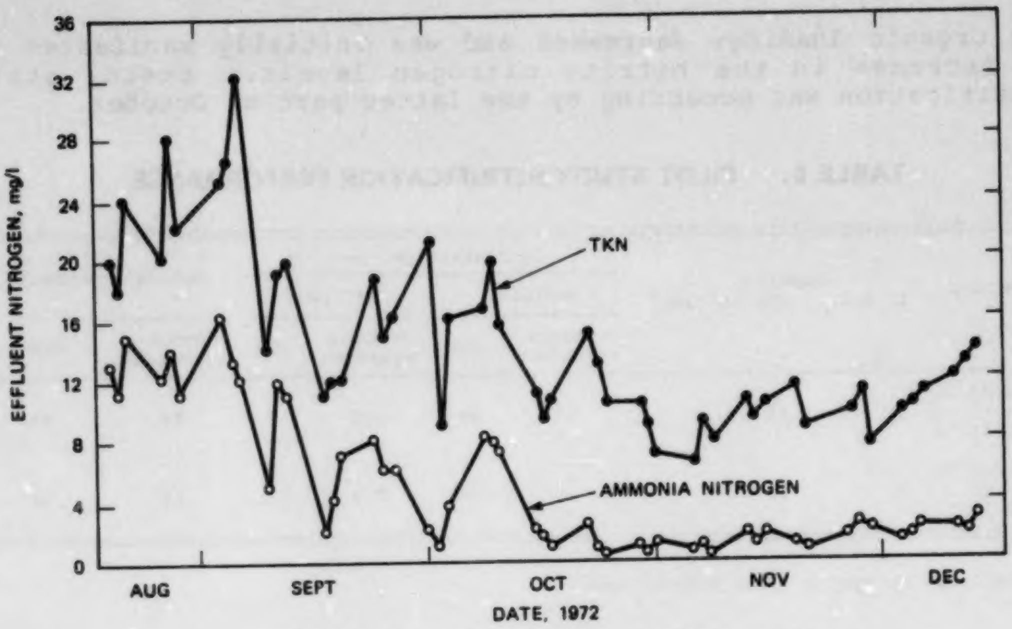
[d] Settled 1 hr in an Imhoff cone.

[e] mgd x 3,785 = m^3/day.

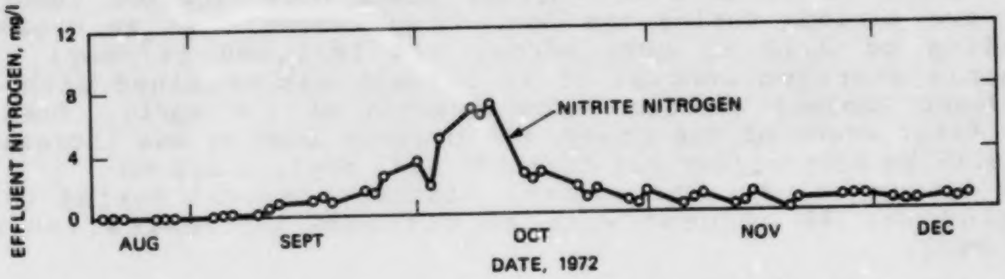
[f] November 1 to December 13, 1972; 0.1-M ammonia nitrogen used.

[g] Ammonia added to nutrient-deficient cannery waste.

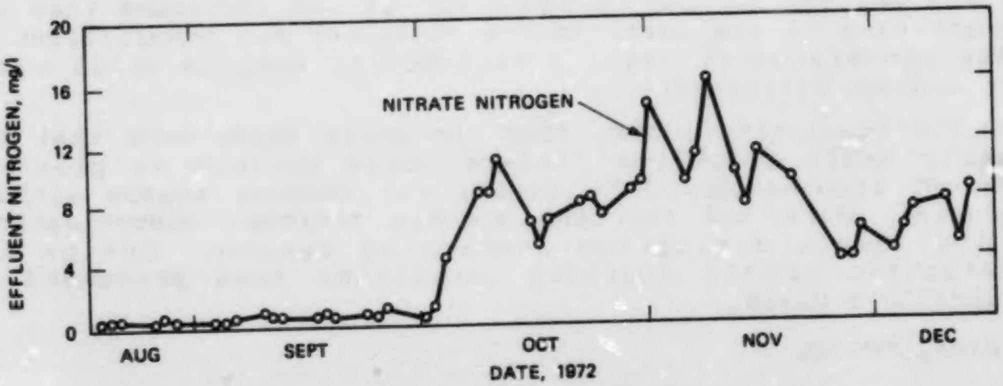
Nitrification performance during the pilot study is summarized in Figure 9 and Table 8. Figure 9 depicts time histories of effluent concentrations for total Kjeldahl nitrogen (TKN), ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen from the canning season through the transition period into the noncanning season. Nitrification began in mid-September when



(a) AMMONIA NITROGEN AND TOTAL KJELDAHL NITROGEN



(b) NITRITE NITROGEN



(c) NITRATE NITROGEN

Figure 9. Pilot study nitrification performance.

the organic loadings decreased and was initially manifested by an increase in the nitrite nitrogen levels. Steady state nitrification was occurring by the latter part of October.

TABLE 8. PILOT STUDY NITRIFICATION PERFORMANCE

Period	Loading, lb BOD_5/1,000 ft^3/day[a]	Concentration, mg/l				Removal, percent	
		Influent		Effluent			
		Ammonia nitrogen	TKN	Ammonia nitrogen	TKN	Ammonia nitrogen	TKN
10/23/72 to 11/21/72	14	17	28	1.0	9.9	94	65
11/27/72 to 12/13/72	22	18	29	2.0	11	89	62

[a] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

Shown in Table 8 are steady state nitrification results for two periods during the noncanning season. At an organic loading of 0.22 kg BOD_5/m^3/day (14 lb/1,000 ft^3/day), an ammonia nitrogen removal of 94 percent was obtained with an effluent ammonia nitrogen concentration of 1.0 mg/l. During the final weeks of the study, the organic loading was increased to 0.35 kg BOD_5/m^3/day (22 lb/1,000 ft^3/ day), close to the design value. The ammonia nitrogen removal during this period was 89 percent with an effluent concentration of 2.0 mg/l.

Although the ammonia nitrogen removals obtained were quite high, organic nitrogen removals were low, averaging 19 percent for the periods covered by Table 8. It was concluded that the contact time of the waste in the biofilter was insufficient to allow conversion of organic nitrogen to ammonia which would then undergo nitrification.

The conclusions drawn from the pilot study were that the plastic media trickling filters could perform as planned, removing carbonaceous BOD_5 during the canning season without producing odors and reducing ammonia nitrogen concentrations to low levels during the noncanning season. Design and constuction of the upgraded facilities then proceeded as originally devised.

PHYSICAL DESIGN

Conversion of the existing trickling filters from rock media to plastic media required, in addition to modifications to the filters themselves, substantial modifications to the filter distribution and collection systems. Provision had to be made in the filters for taller, heavier center columns and rotary distributors, for air inlet ducts and fans, and for a plastic media support system. Other changes included addition of pumps and major distribution lines, routing of foul air from the plant headworks through two of the plastic-media filters for odor control, and addition of electrical controls.

Filter Walls and Rotary Distributors

In order to retain the existing filter foundations, a light-weight wall was used to contain the plastic media. The original filter walls were solid concrete 2.0 m (6.5 ft) high; the new walls are 8.8 m (29 ft) high. A concrete-block wall was built on top of the existing wall as shown in Figure 10. Three layers of concrete blocks are separated by 20-cm (8-in.) high sections of solid concrete; the walls are capped by a reinforced concrete tension ring.

Three characteristics of the concrete-block construction make the selection of a sealer for the filter walls critical: (1) the blocks are porous and thus absorb the sealer as it is applied, (2) expansion and contraction of the wall can cause cracking in the sealer, and (3) the concrete blocks tend to transmit fluids by capillary action. A coal-tar epoxy was used to seal one of the filters but leaks developed soon after startup (see Section 6). A thin film of polyurethane was used on the other two filters; polyurethane was selected because it does not contain volatile solvents, which would produce bubbles in the film, and it stays soft and elastic. This reduced leakage drastically but did not completely eliminate it.

The new taller center column required a new foundation. An 1.7-m^2 (18-ft^2) slab was removed from the center of the existing foundation to allow excavation and construction of the new foundation. Filters No. 5 and 6 incorporate a foul-air distribution chamber in the center column foundation; a 1.22-m (48-in.) diameter foul-air duct under the filter floor terminates at the distribution chamber. Section views of the center columns are shown in Figure 11. The existing 0.91-m (36-in.) diameter filter supply line was determined to be sufficiently large to handle the increased flows and was retained. The center column has an inner diameter of 1.2-m (4.0 ft) and an outer diameter of 2.0 m (6.5 ft). It has an overall height of approximately 7.6 m (25 ft), 1.8 m (6 ft) of which is below the filter foundation.

New Walker Process rotary distributors were installed on the center columns (Figure 12). At the center, the four arms are connected to a center column assembly composed of the support column for the truss guide-wires, an outer cylinder, two inner weirs, and a waterproof thrust-bearing assembly. The

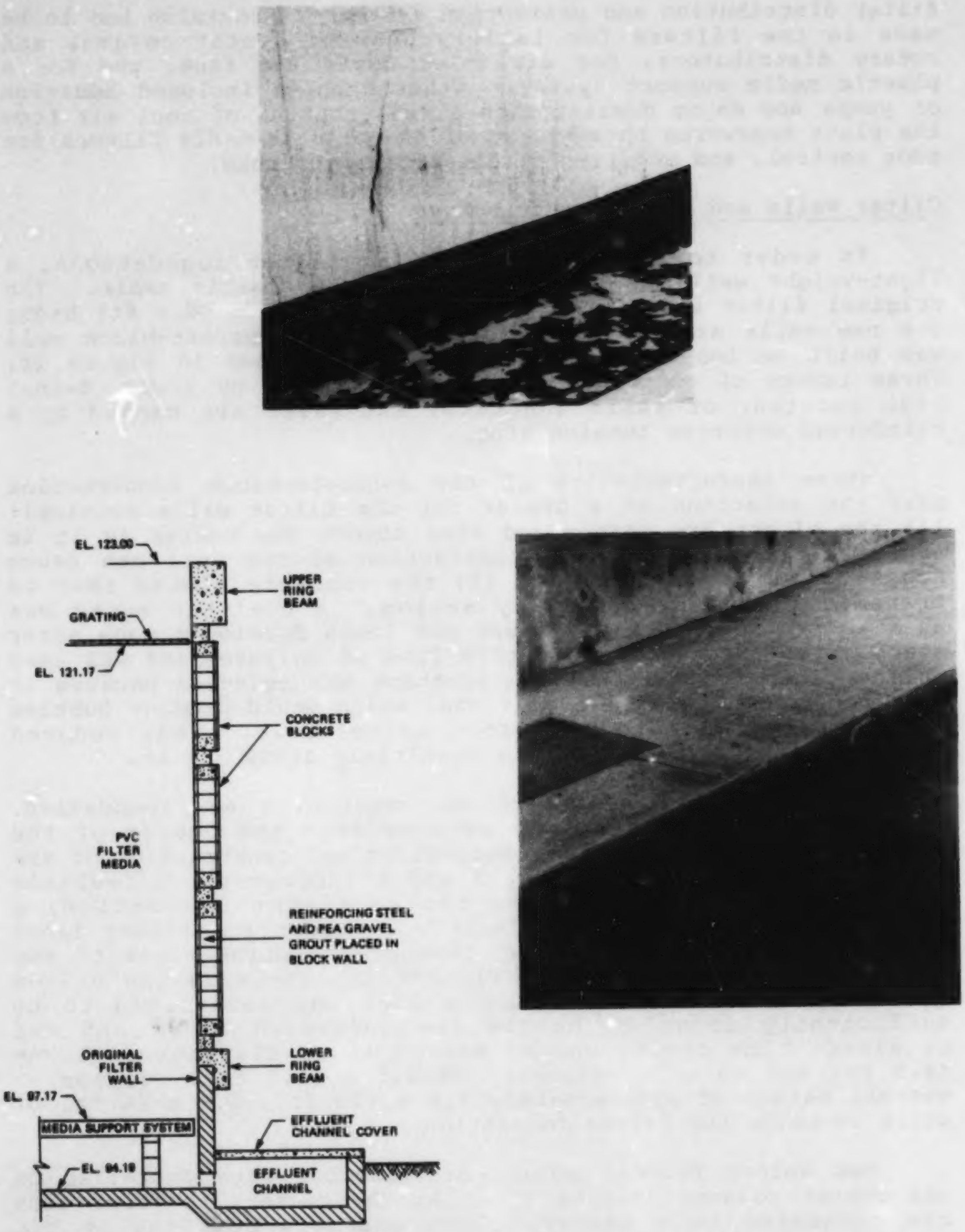
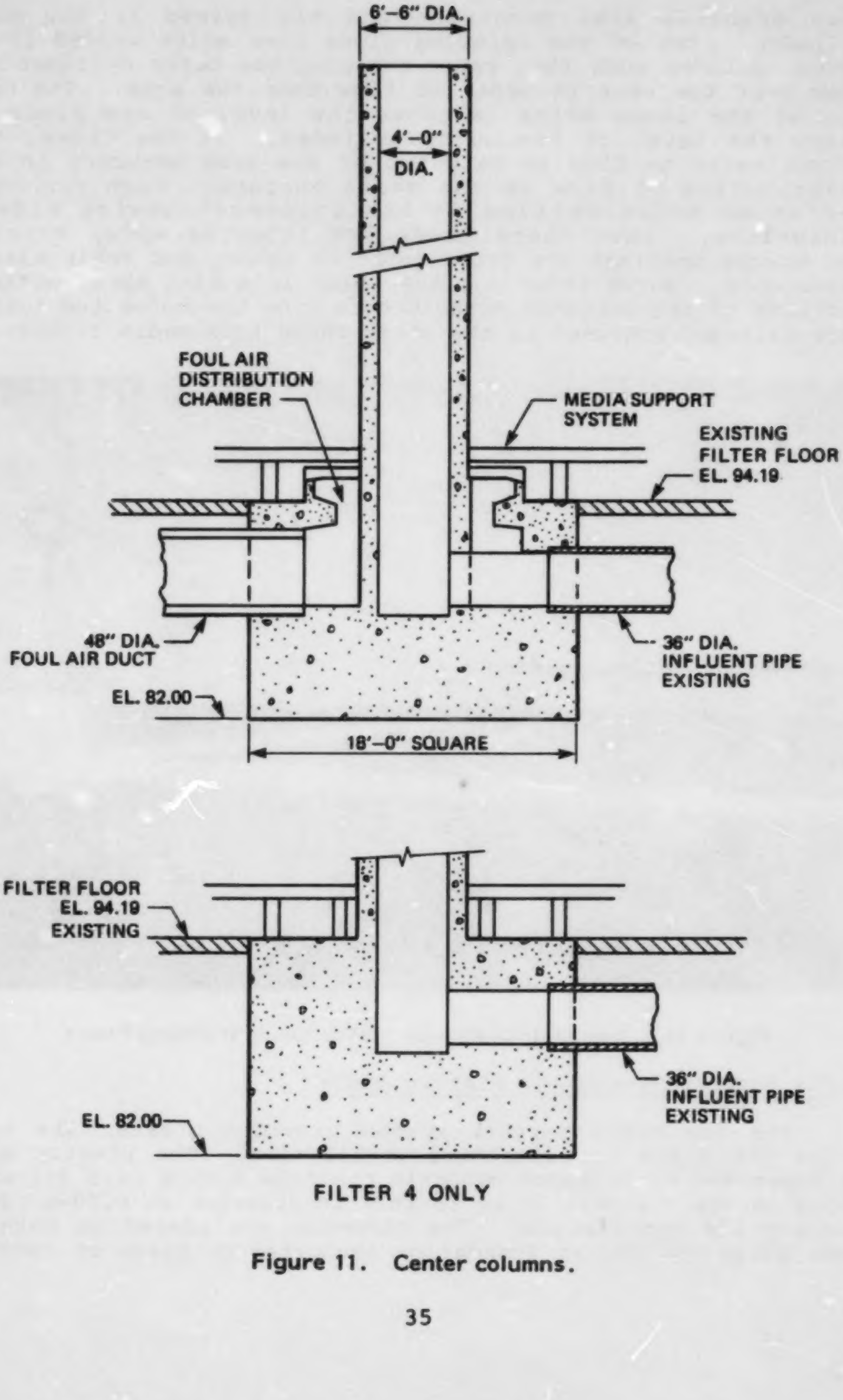


Figure 10. Trickling filter sidewall and effluent collection channel. Photographs show collection channels before and after conversion.


6'–6" DIA.
4'–0" DIA.
FOUL AIR DISTRIBUTION CHAMBER
MEDIA SUPPORT SYSTEM
EXISTING FILTER FLOOR EL. 94.19
48" DIA. FOUL AIR DUCT
36" DIA. INFLUENT PIPE EXISTING
EL. 82.00
18'–0" SQUARE
FILTER FLOOR EL. 94.19 EXISTING
36" DIA. INFLUENT PIPE EXISTING
EL. 82.00

FILTER 4 ONLY

Figure 11. Center columns.

four opposing arms penetrate and are joined to the outer cylinder. Two of the opposing pipes have weirs welded to the outer cylinder such that water entering the outer cylinder must flow over the weir in order to flow into the arms. The upper rim of the inner weirs is above the level of the pipes but below the level of the outer cylinder. At low flows, this allows water to flow in only two of the arms ensuring an even distribution of flow to the media surface. Each arm has a series of holes drilled in its counterclockwise side at centerline. Into these holes are inserted spray nozzles. The nozzle openings are rectangular in shape, and their size is adjustable. Water flows out the holes in a flat spray pattern. Portions of the original distributors from the converted filters were salvaged and used in the other three rock media filters.

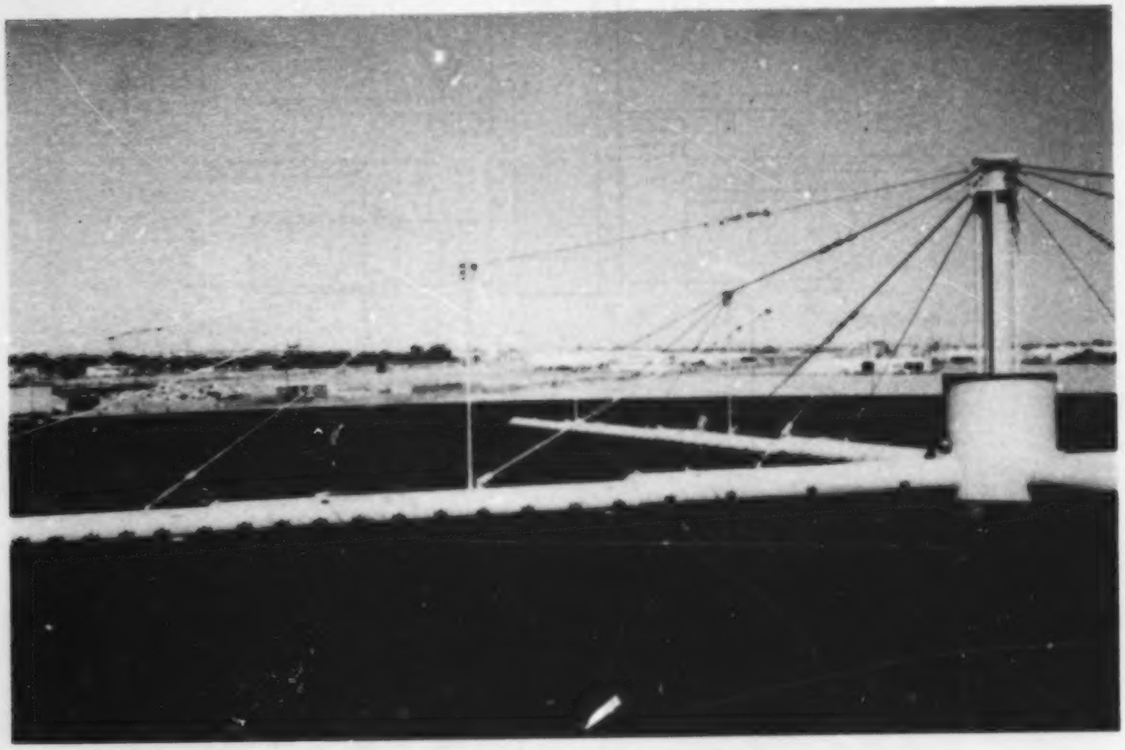


Figure 12. New distributors for plastic media trickling filters.

Media Support System and Plastic Media

The new media support system provides greater air space below the media for increased ventilation. The plastic media is supported by U-shaped concrete channels 0.46 m (1.5 ft) wide. Holes in the channels 20 cm (8 in.) in diameter at 0.60-m (2-ft) spacing aid ventilation. The channels are placed in parallel rows along the filter foundation supported by piers of concrete blocks which are keyed into the foundation with dowels (Figure 13). Concrete blocks were used for economy since large quantities of concrete blocks were used for the filter walls. Details of the media support system are shown in Figure 14.

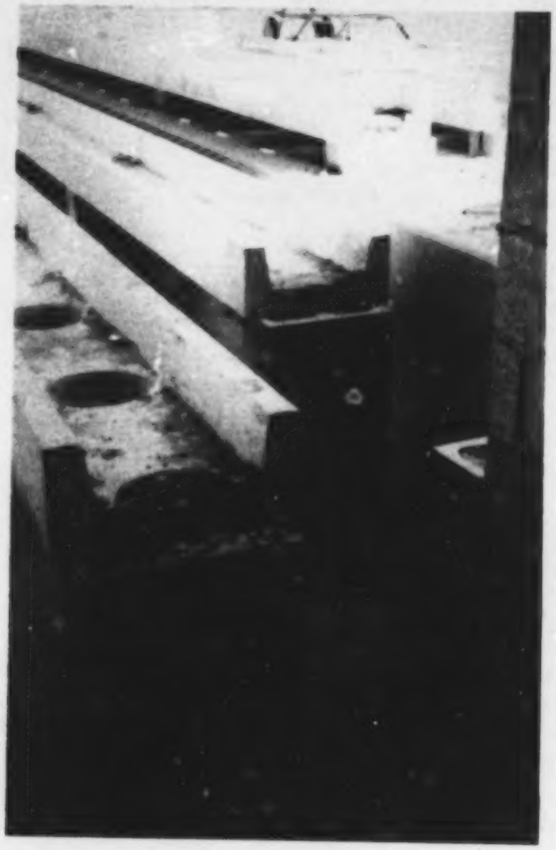


Figure 13. Media support system.

Clearance between the bottom of the plastic media and the filter floor is 0.91 m (3 ft) except over the air inlet ducts and fan-housing enclosures. Media support channels were placed on 10-cm (4-in.) high supports over the ducts, as shown in Figure 14. The increase in elevation of the bottom of the plastic media over the ducts is 0.30 m (1 ft).

The plastic media used in the filters was Vinyl Core, manufactured by B. F. Goodrich. The polyvinyl chloride (PVC) media comes in modules (0.61 m x 0.61 m x 1.22 m, or 2 ft x 2 ft x 4 ft); the blocks are cut to fit around the center column and the filter walls. The lower modules were made from PVC sheets of greater thickness to provide higher strength. The modules were installed in alternating layers, with each layer composed entirely of one type of module. The pattern of the media modules differed for odd and even layers to prevent short-circuiting of the wastewater. A plastic grating was placed over the top of the last layer. The overall depth of the media is 6.7 m (22 ft).

Air Flow

A forced-air ventilation system was provided in the plastic media filters to maintain aerobic conditions. Four air inlet ducts were constructed on each filter foundation at 90-degree spacings. The ducts extend from the outer walls of the filter inward toward the center column. Each duct is 2.1 m (7 ft) wide by 0.91 m (3 ft) high. A piece of the original filter wall was removed opposite each duct to allow for the installation of fans. Two fans supply each duct as shown in

Figure 15. The fans are axial-flow, constant-speed types and were manufactured by the Pennsylvania Ventilator Company. They are driven by Westinghouse 3.7-kW (5-hp) motors. Manual controls are provided for each fan. Holes in the air inlet ducts allow the air from outside to reach the filters; air is forced by the fans up through the plastic media from below. Upward air flow is approximately 1.8 $m^3/min/m^2$ (6 cfm/ft^2) with all fans operating.

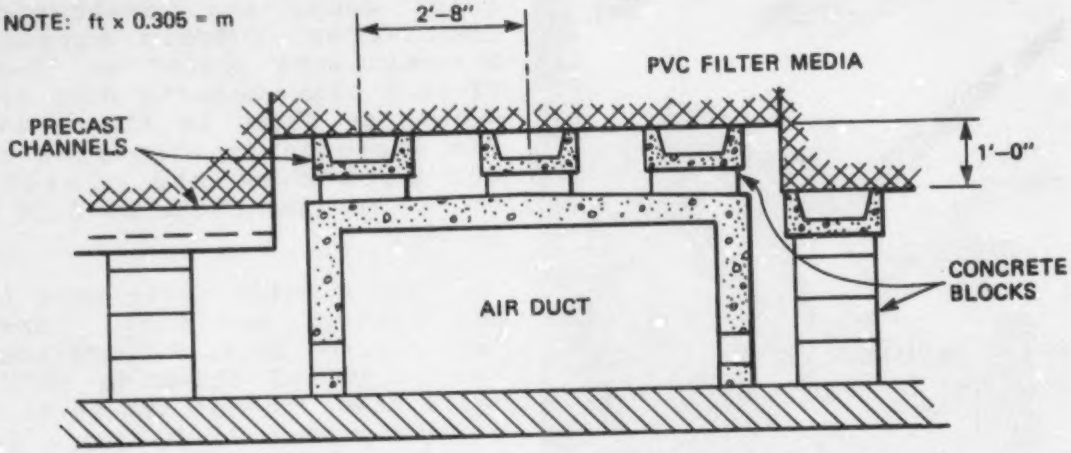


Figure 14. Media support system details.

In addition to the fresh-air ventilation, filters No. 5 and 6 receive foul air from the headworks of the plant. Foul air flows through 1.2-m (48-in.) ducts beneath the foundation to the foul-air distribution chamber in the center column foundation. The foul air is deodorized by biological oxidation as it rises through the plastic media.

Effluent Collection System

In order to provide increased effluent collection capacity, an external collection pipe system was added to each plastic media filter. The external collection system consists of two effluent collection boxes at opposite sides of the filter and 0.91-m (36-in.) diameter effluent collection pipes leading to a filter return box at the original filter return pipe connection (Figures 16 and 17). The original collection system consisted of an open channel 0.60 m (2 ft) deep surrounding the filter wall and sloping toward the filter return pipe. The channel width varies from its maximum width near the filter return pipe, to accommodate the accumulated flow, to a minimum on the opposite side of the filter, coinciding with the high point of the channel bottom. This existing channel was covered during conversion to ensure that ventilation air would be forced up through the media and not out into the collection channel (see Figure 10).

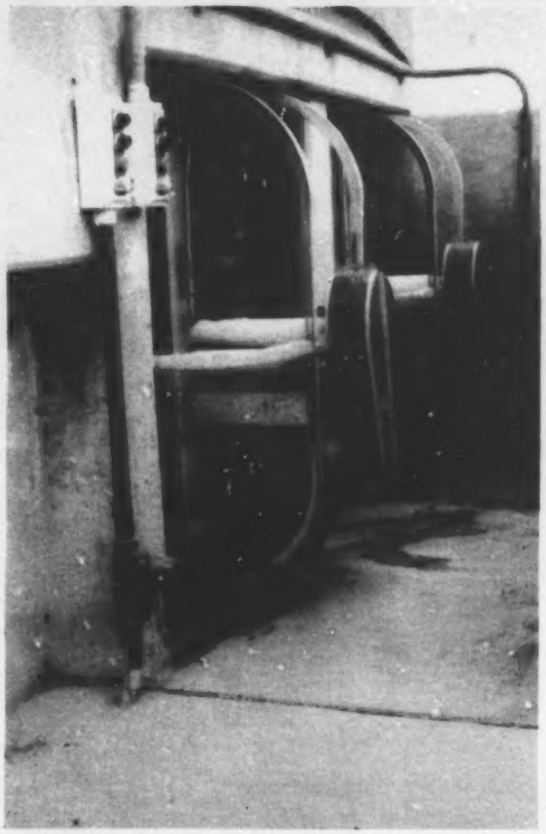


Figure 15. Plastic media filter fans.

At two separate locations, each 90 degrees from the filter return pipe, a portion of the bottom of the original effluent channel was removed and an effluent collection box constructed. The bottom elevation of the box, which is the same as the 0.91-m (36-in.) collection pipe invert elevation, is over 1.22 m (4 ft) below the original channel bottom.

Effluent from the side opposite the filter return box flows along the channel to the collection boxes; it then drops down into the boxes and flows through the effluent collection pipes to the filter return box. Effluent entering the channel between the collection boxes and the return box continues in the original channel and enters the filter return box through a portion of the original filter return pipe. Effluent then flows from the return box to the filter distribution structure through new 1.22-m (48-in.) diameter pipes.

Filter Distribution Structure No. 1 and Piping

The existing filter distribution structure was enlarged and modified extensively to provide for increased capacity and better control. An isometric view of the original structure is shown in Figure 18 and the modified structure is shown in Figure 19.

Distribution Structure Functions--

The four major functions of the distribution structure are:

(1) To combine primary effluent with recycled trickling filter effluent and distribute it to the individual filters,

(2) To control filter effluent recirculation to maintain a constant flow to the filter,

(3) To discharge effluent to the secondary sedimentation tanks, and

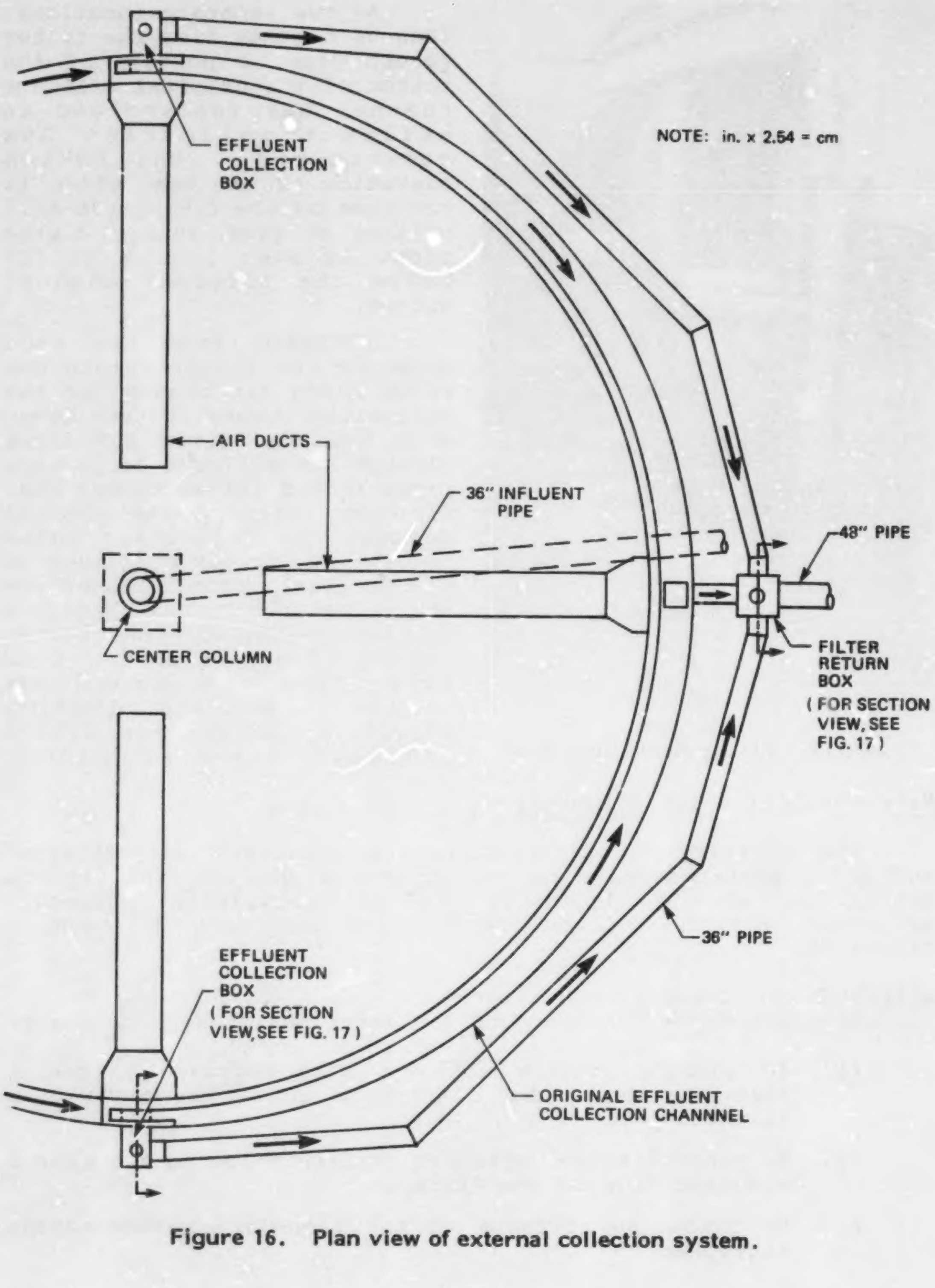
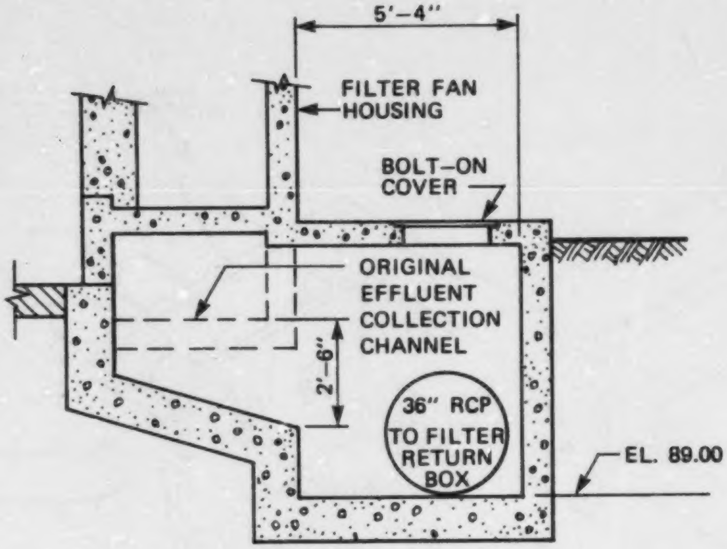
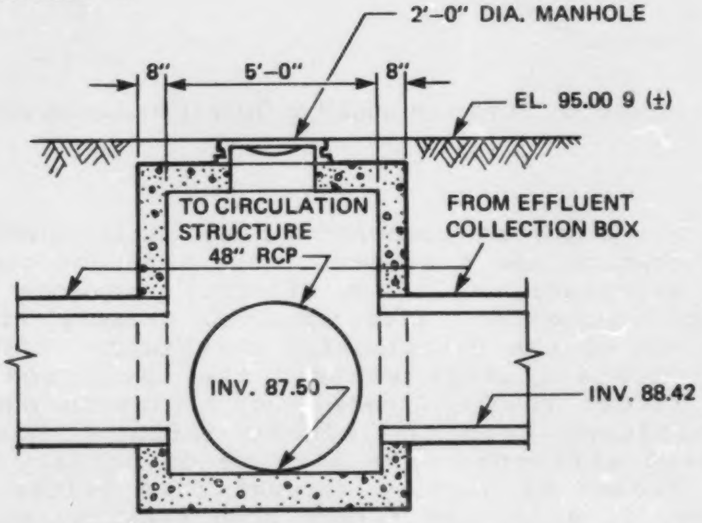

EFFLUENT COLLECTION BOX
NOTE: in. x 2.54 = cm
AIR DUCTS
36" INFLUENT PIPE
48" PIPE
CENTER COLUMN
FILTER RETURN BOX (FOR SECTION VIEW, SEE FIG. 17)
36" PIPE
EFFLUENT COLLECTION BOX (FOR SECTION VIEW, SEE FIG. 17)
ORIGINAL EFFLUENT COLLECTION CHANNNEL

Figure 16. Plan view of external collection system.


5'–4"
FILTER FAN HOUSING
BOLT–ON COVER
ORIGINAL EFFLUENT COLLECTION CHANNEL
2'–6"
36" RCP TO FILTER RETURN BOX
EL. 89.00

EFFLUENT COLLECTION BOX

NOTES: in. x 2.54 = cm
ft x 0.305 = m



FILTER RETURN BOX

Figure 17. Section views of effluent collection box and filter return box.

(4) To provide sufficient head to supply effluent to the rock media filters by gravity.

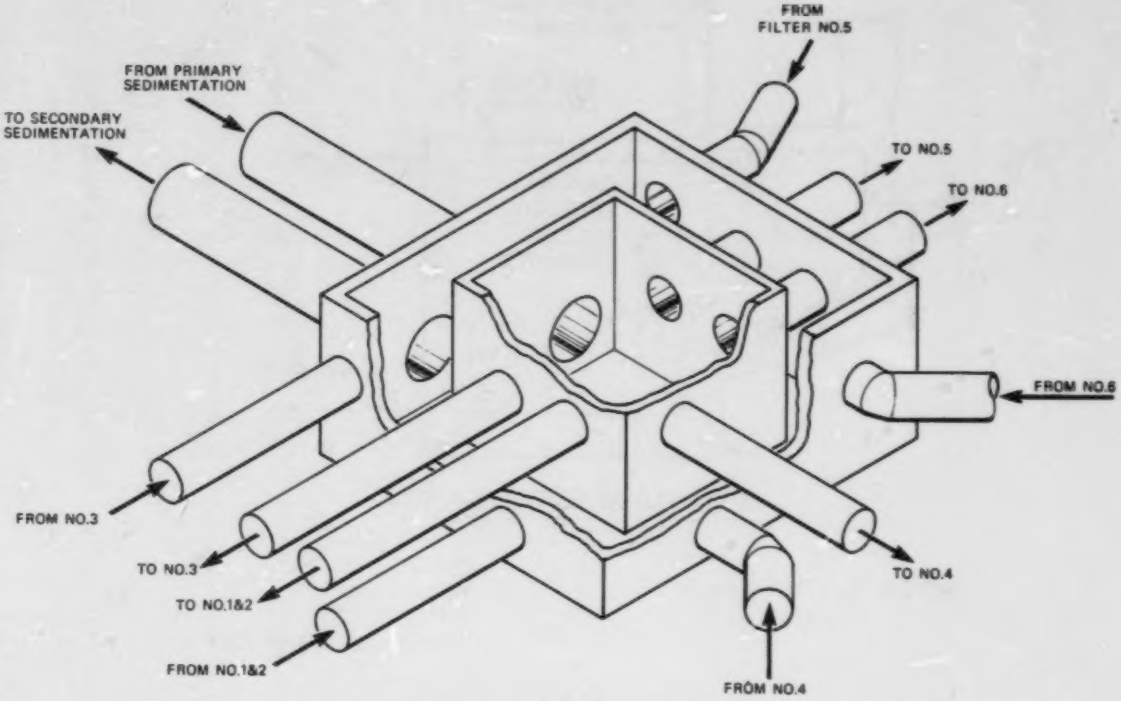


Figure 18. Original trickling filter distribution structure.

The structure is composed of two main chambers: an outer effluent chamber and a higher, inner influent chamber. In the original structure, a 1.52-m (60-in.) diameter line from the primary sedimentation tanks supplied primary effluent to the influent box of the distribution structure. Effluent from the six rock media filters entered the outer box through five separate filter return lines. Recirculation pumps lifted the filter effluent into the higher influent box to mix with the primary effluent. The mixture of primary and secondary effluent flowed by gravity through five filter supply lines. Filters No. 3, 4, 5, and 6 each have separate supply lines. A smaller distribution structure located between filters No. 1 and 2 distributes the flow from one line between the two filters and combines the effluent from the two filters to return it to the larger structure. This smaller distribution structure was not modified. A plan view of the area and major pipelines is shown in Figure 20.

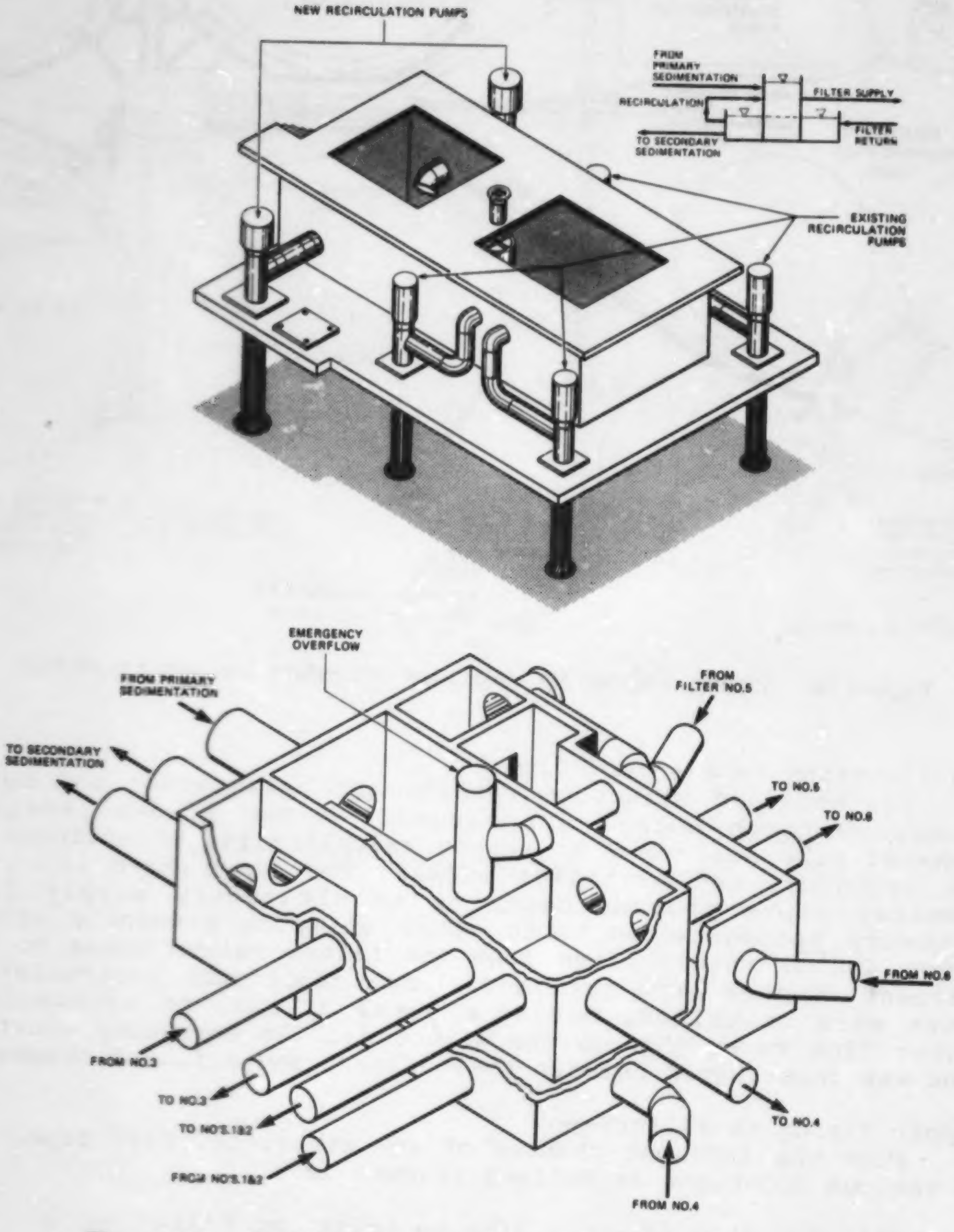


Figure 19. Modified trickling filter distribution structure.

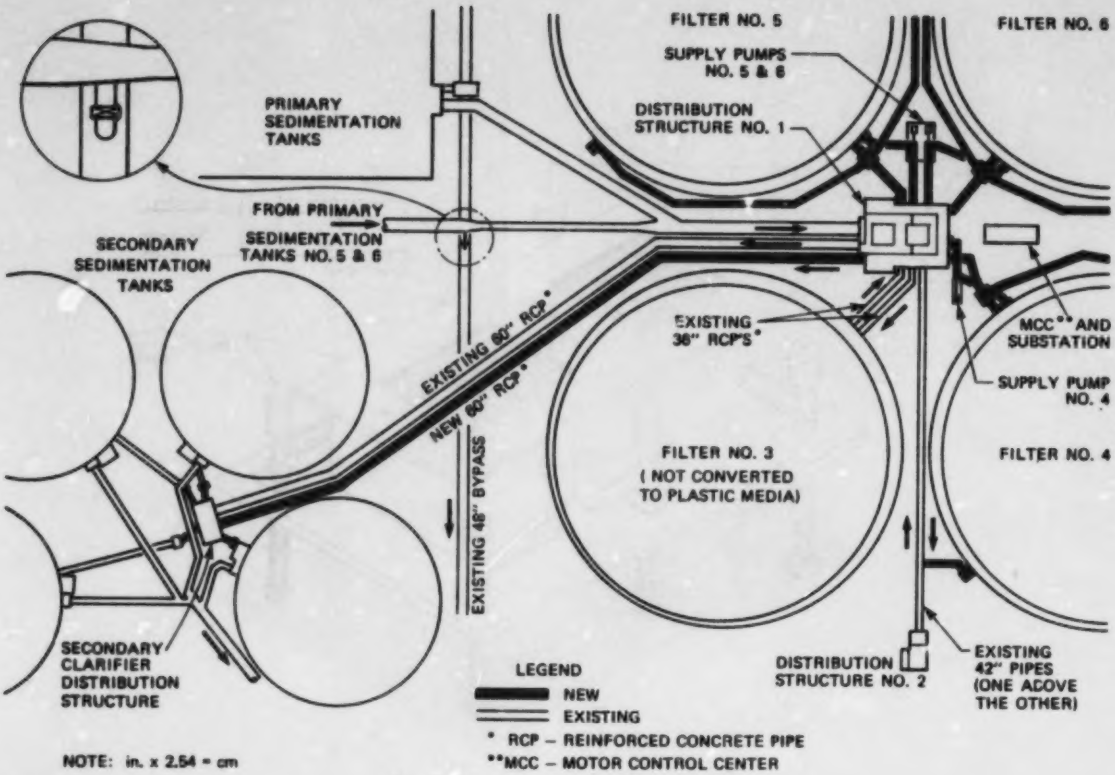

FILTER NO. 5
FILTER NO. 6
SUPPLY PUMPS NO. 5 & 6
PRIMARY SEDIMENTATION TANKS
DISTRIBUTION STRUCTURE NO. 1
FROM PRIMARY SEDIMENTATION TANKS NO. 5 & 6
SECONDARY SEDIMENTATION TANKS
EXISTING 36" RCP'S*
MCC** AND SUBSTATION
EXISTING 60" RCP*
NEW 60" RCP*
SUPPLY PUMP NO. 4
FILTER NO. 3 (NOT CONVERTED TO PLASTIC MEDIA)
FILTER NO. 4
EXISTING 48" BYPASS
SECONDARY CLARIFIER DISTRIBUTION STRUCTURE
LEGEND
NEW
EXISTING
* RCP – REINFORCED CONCRETE PIPE
**MCC – MOTOR CONTROL CENTER
DISTRIBUTION STRUCTURE NO. 2
EXISTING 42" PIPES (ONE ABOVE THE OTHER)
NOTE: in. x 2.54 = cm

Figure 20. Piping diagram for upgraded secondary treatment facilities.

Modifications to the Structure--

The modified structure retains the basic inner and outer boxes, although both are enlarged. A new 1.52-m (60-in.) diameter pipe was added to supply trickling filter effluent to the secondary sedimentation tanks. The two 1.52-m (60-in.) diameter pipes provide capacity to ultimately supply five secondary sedimentation tanks, four of which presently exist. Larger filter return lines from the filter return boxes to the effluent chamber were provided. Two additional recirculation pumps were installed, making a total of six, to accommodate higher flow rates through the structure. An emergency overflow line was constructed between the influent and effluent chambers.

Supply Piping to Filters--

From the influent chamber of the structure, five pipes run to various locations as follows (Figure 19):

(1) A 0.91-m (36-in.) line to trickling filter No. 3

(2) A 1.07-m (42-in.) line to trickling filter distribution structure No. 2

(3) A 0.91-m (36-in.) line to trickling filter No. 4 supply pump

(4) A 0.91-m (36-in.) line to trickling filter No. 5 supply pump

(5) A 0.91-m (36-in.) line to trickling filter No. 6 supply pump

These five pipes have manually-operated, isolating sluice gates located inside the influent chamber.

Return Piping from Filters--
There are five pipes that enter the effluent chamber from various locations as follows:

(1) A 0.91-m (36-in.) line from trickling filter No. 3

(2) A 1.07-m (42-in.) line from trickling filter distribution structure No. 2

(3) A 1.22-m (48-in.) line from trickling filter No. 4

(4) A 1.22-m (48-in.) line from trickling filter No. 5

(5) A 1.22-m (48-in.) line from trickling filter No. 6

These lines have no isolating sluice gates.

Emergency Overflow Line--
A 0.76-m (30-in.) diameter pipe from the influent chamber to the effluent chamber of the structure provides for emergency overflow. The influent end of the pipe terminates at a vertical 0.91-m (36-in.) diameter pipe section, the upper end of which is at elevation 102.00. Mounted inside the vertical section is a 1.07-m (42-in.) long telescoping weir pipe section. It is attached to a pedestal-mounted operator by means of a threaded valve stem. The operator is a manually operated handwheel located on the center walkway atop the structure. The weir elevation is adjustable between elevation 102.00 and 105.25.

Trickling Filter Supply--
The rock media filters are gravity fed. The water level in the influent chamber determines the head on the rock media filter distribution system; a higher water level results in a higher flow to the filters. The water level is adjusted by varying the set point for operation of the recirculation pumps.

Since the plastic media filters are over 6.1 m (20 ft) taller than the original filters, each must be supplied by an influent supply pump. The change in water surface elevation in the influent chamber is small relative to the operation head of the supply pumps (on the order of 0.6m/6.7m or 2 ft/22 ft); thus, the fluctuations which control the rock media supply rates have little effect on supply to the plastic media filters.

Chlorine Solution Supply--

A chlorine solution supply line terminates at a hose bib at the southwest corner of the structure. By employing hoses, chlorine may be added to either the influent or effluent chambers. When added to the influent chamber, chlorine is used for filter fly control; when added to the effluent chamber, it is used for foam control.

Recirculation and Trickling Filter Supply Pumps

Conversion to the plastic medic filters required the addition of five pumps: three pumps to supply the converted filters and two additional recirculation pumps for increased flows.

Recirculation Pumps--

Recirculation of trickling filter effluent is accomplished by pumping wastewater which enters the distribution structure effluent box into the influent box to mix with incoming primary effluent. Six vertical, motor-driven, fixed-speed, axial-flow pumps are located around the periphery of the upper structure (influent chamber) atop the effluent chamber. The four small pumps at the east end of the structure were part of the original equipment. These four pumps discharge directly into the influent chamber above the maximum water level. At the west end of the structure are two new one-stage Johnston vertical pumps, Model 24PO (see Figure 19 for pump locations). The new pumps have a rated design capacity of 1,060 l/sec (16,800 gpm) against a total dynamic head of 3.4 m (11 ft) at 700 rpm. They discharge into the effluent chamber below the minimum water level. Local manual controls for each pump are located on the structure wall adjacent to the pump. The feeders and the remote controls for the pumps are located in cubicles in the main motor control center (MCC) in the operations building.

A conductance-type level probe is mounted on the east inside wall of the influent chamber which measures the water level in the influent chamber and transmits a signal to the level controller located at the main MCC. When the individual pump selector switches are set for automatic operation, the level controller will start and stop the recirculation pumps remotely. Since the recirculation pumps are a fixed-speed type, recirculation flow rate is controlled by varying the number of pumps in operation.

Trickling Filter Supply Pumps--

Each variable-speed trickling filter supply pump is located between the distribution structure and the plastic media filter which it supplies (see Figure 20 for pump locations). Each is a Johnston vertical pump, Model 24PS, with a rated capacity of 1,060 l/sec (16,800 gpm) against a total dynamic head of 7.3 m (24 ft) at 700 rpm. The drive unit is a 1750-rpm, 112 kW (150-hp), Reliance electric motor, integral with a variable-speed hydraulic drive directly coupled through an in-line gear reducer. The gear reducer employs helical gears to give a reduction ratio of 2.5 to 1. The pumping rate is controlled by manual adjustment of the variable-speed hydraulic unit.

Secondary Sedimentation Tank Distribution Structure--
The original secondary sedimentation tank distribution structure was replaced by an entirely new structure. The new structure was designed to accommodate a second 1.52-m (60-in. diameter influent line from the filter distribution structure and a future fifth secondary sedimentation tank; the fifth effluent line will remain capped until the fifth tank is constructed. New 1.07-m (42-in.) square sluice gates were installed at each sedimentation tank supply line. The sluice gates are manually controlled from the top of the structure.

Motor Control Center (MCC) and Electrical System--
A new MCC and trickling filter substation were installed next to the filter distribution structure for the blowers and supply pumps. Modifications to the existing electrical system had to be made to provide for the new controls and to provide power to the new pumps.

MISCELLANEOUS ASPECTS UNIQUE TO STOCKTON

Several aspects of the Stockton design were unique to that situation and may not be applicable in other instances. These are mostly due to the existence of the oxidation ponds following secondary treatment. A temporary deterioration in secondary effluent quality does not cause a dropoff in overall plant performance. This allowed the trickling filter distribution structure No. 1 to be shut down for 3 mo while construction was taking place; primary effluent was bypassed to the oxidation ponds during that period. In other situations, secondary treatment might need to be continued during the construction period.

Another unique aspect of the Stockton design is that each plastic media biofilter is fed by a single supply pump. If a pump is shut down for repairs, the associated biofilter must also be shut down. A more conventional design (and one which might be difficult to implement in an upgrading situation) would be to provide a common supply header between the supply pumps and the biofilter. In that situation, shutdown of one pump would not reduce the number of operating filters. The buffering effect of the Stockton oxidation ponds allowed a simpler, less costly design to be used.

A final point (not related to the oxidation ponds) concerns the retention of the original 0.91-m (36-in.) influent feed lines under the biofilters. Although these had deteriorated and required repair, they were sufficiently large to permit their use with the higher flows. At other plants, excessive deterioration or insufficient size might necessitate their replacement.

SECTION 6

CONSTRUCTION AND STARTUP

Modifications to an existing wastewater treatment plant impose added constraints compared with construction of a new facility. An acceptable level of treatment performance must be maintained even when structures which require modification are bypassed. At Stockton, the availability of oxidation ponds made bypassing of the entire secondary treatment facilities possible during the noncanning season without violation of discharge requirements. The heavy seasonal loading on the Stockton plant by local canneries created a time constraint; with construction starting in January, four filters, including one plastic media filter, had to be back in service prior to July.

Maximum utilization of existing structures required unique designs as discussed in the previous section. Using existing structures also created construction problems; portions of the original structures had to be demolished and parts had to be salvaged, and some parts which were initially thought to be reusable had to be replaced. Unforeseen deterioration to some facilities also necessitated repairs.

PRECONSTRUCTION PHASE

The construction contract for the trickling filter conversion was advertised for bidding twice. The first bids, opened on November 28, 1972, were more than 20 percent over the engineer's estimate. Reasons for the high bids were probably: (1) extra labor costs to meet the tight time schedule, (2) the possibility of penalties for failure to meet the time schedule, and (3) possible penalties for treatment interruption related to bypassing of secondary facilities. The City of Stockton rejected the first bids.

The second set of bids was opened on December 15, 1972. Table 9 shows the three low bidders and the amounts of the bids. The low bid of $1,722,000 by the joint venture company Caputo-COAC was found to be in order, and Caputo-COAC was awarded the contract.

The successful contract bid included furnishing all labor, materials (excluding the media itself), and equipment for the conversion of three filters to plastic media; repairs to the other three filters; modifications to the filter distribution structure; and the secondary sedimentation tank distribution structure; electrical modifications; and pump installations. The bid also included $50,000 for contingencies.

TABLE 9. LOW BIDDERS FOR MODIFICATIONS TO SECONDARY TREATMENT FACILITIES

Order	Bidder	Bid amount, dollars
1	Caputo-COAC, San Jose	1,722,000
2	Homer J. Olsen, Inc., Union City	1,793,000
3	DeNarde Construction Co., San Francisco	1,819,000

The contract for supplying and installing the plastic media was also bid twice. The first bids were nullified because the affadavit of noncollusion was inadvertently left out of the set of documents given to the bidders. The second set of bids was opened on December 15, 1972. Table 10 summarizes the three low bids, the bid amounts, and the media manufacturers. The bid by the Linford Mechanical Company was for a single filter, using redwood rather than plastic media. The contract was awarded to the Lomar Corporation, which, possessing a California contractor's license, represented B. F. Goodrich, a plastic media manufacturer. A representative of the Ethyl Corporation protested the bid award, claiming that the B. F. Goodrich media did not meet specifications, specifically that it had not been used in a comparable operation for 2 yr. The city's consulting engineer decided that the Ethyl Corporation misinterpreted the specifications, and the bid award was upheld.

TABLE 10. LOW BIDDERS FOR FILTER MEDIA SUPPLY AND INSTALLATION

Order	Bidder	Bid amount, dollars	Media type	Media manufacturer
1	Lomar Corporation, Santa Ana	1,839,930	Plastic	B. F. Goodrich
2	Linford Mechanical Co., Oakland	713,789[a]	Redwood	Del Pak
3	COAC, Inc., Milbrae	2,316,000	Plastic	Ethyl Corporation

[a] For filter No. 6 only.

Major equipment items were selected and ordered immediately after bid awards. These items included the trickling filter supply pumps, the recirculation pumps, the rotary distributors, and the new MCC. The major equipment list submitted by

Caputo-COAC is presented in Table 11. The manufacturers selected by the city were: (1) Johnston Pump, (2) Johnston Pump, (3) Walker Process, and (4) Westinghouse.

TABLE 11. MAJOR EQUIPMENT SUPPLIERS SUBMITTED BY GENERAL CONTRACTOR

Description	Manufacturer	Installed price, dollars	Guaranteed delivery time, days
1. Trickling filter supply pumps	Johnston Pump	65,000	150
	Fairbanks Morse	Not available	-
2. Trickling filter recirculation pumps	Johnston Pump	25,000	150
	Fairbanks Morse	Not available	-
3. Rotary distributors	Walker Process	125,000	140
	Pacific Flush Tank	Not available	-
	Enviro Tech	125,000	150
4. Motor control center	Cutler-Hammer	25,000	175
	General Electric	Not available	-
	Delta Switchboard	22,250	150
	Westinghouse	22,000	150
	Sierra Switchboard	21,750	150

The first preconstruction conference was held on January 10, 1973. A change order was agreed upon allowing the contractor to substitute filter No. 4 for No. 5 in the construction schedule; this filter was to be converted first, before the start of the canning season. Brown and Caldwell was retained to inspect construction and review shop drawings. The contractor submitted a detailed cost breakdown which was subsequently revised. The revised cost breakdown, is presented in Section 7.

CONSTRUCTION PHASE

The construction schedule for the Stockton plant was determined by the need to have four trickling filters on line by the start of the canning season to avoid overloading the oxidation ponds. One plastic media filter (No. 4) and the remaining three rock media filters were scheduled to be in service by the end of June 1973. The three filters which were to be converted to plastic media were shut down in January 1973, the beginning of the construction phase.

Modifications to the distribution structures required that all the secondary facilities be bypassed. Primary effluent was bypassed to existing oxidation ponds for secondary treatment; a bypass period of 90 days was allowed in the construction specifications. Repairs to the rock media filters were also made during the bypass period.

Construction Sequence

A Critical Path Method (CPM) analysis of the construction activities required to put the four trickling filters on line before the canning season is shown in Figure 21. The CPM chart is usually made to determine the shortest length of time in which construction can be completed. Major time constraints are blocked in, and then other activities are added in the logical construction sequence, allowing a certain number of days to complete each item. Solid lines on the chart indicate fixed times between events. Dotted lines indicate "float" times for particular activities; e.g., the electrical modifications could have been done anytime from the start of the contract to the time that the pumps arrived. In fact, the electrical modifications were spaced out to cover almost the entire float time, although they could have been done in less time.

The CPM chart in Figure 21 was constructed after project completion to illustrate the construction sequence and to show the interrelationships between construction elements. The length of each box represents the approximate amount of time that the activity required. Some events shown in the boxes overlapped slightly; they have been separated for clarity in presentation.

The vertical dotted lines indicate major milestones in progress toward putting the four filters back on line. These milestones are: (1) shutdown of the filters to be converted to plastic media, (2) the beginning of the scheduled 90-day bypassing of secondary facilities, (3) completion of major structural modifications to filter No. 4, which allowed the plastic media installation contractor to begin work, and (4) the end of bypassing when the four filters were back on line.

Modification of filters No. 5 and 6 was initiated during and extended beyond the time period covered by the chart. Construction activities for these two filters are, for clarity of presentation, not shown on the chart.

The critical path is the sequence of events which determines the minimum time required for construction. The heavy dark line in Figure 21 shows the critical path for this project. A procurement time of 160 days for the pumps was the major contribution to the critical path time period. Once the pumps arrived, the time required for their installation determined the length of the critical path; all major structural work on the filter distribution structure was completed before the pumps arrived. Long procurement times for mechanical equipment was a chronic problem around 1973. If more normal delivery times had been experienced, the modification to trickling filter No. 4 would have been on the critical path.

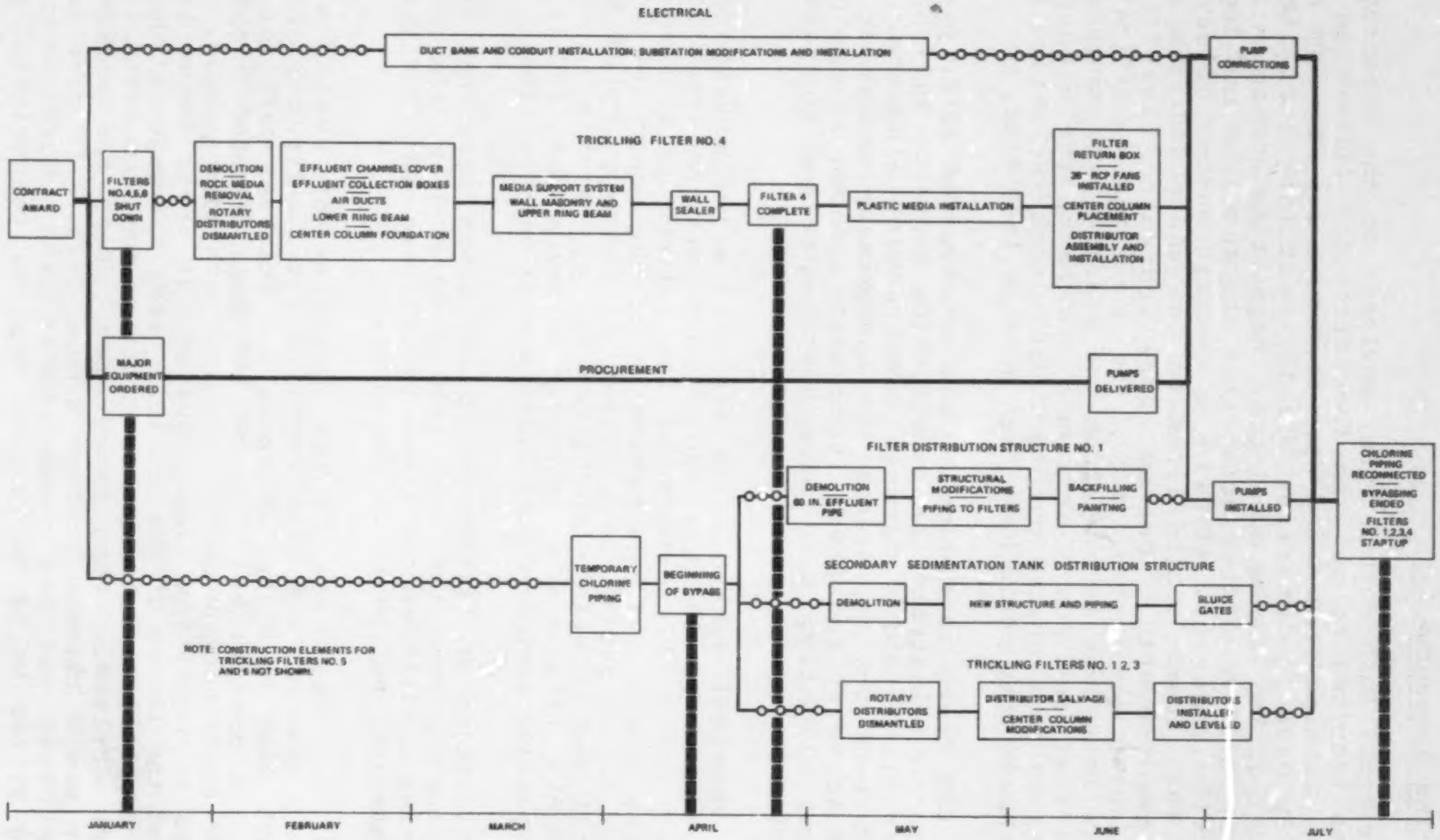

ELECTRICAL
DUCT BANK AND CONDUIT INSTALLATION; SUBSTATION MODIFICATIONS AND INSTALLATION
PUMP CONNECTIONS
TRICKLING FILTER NO. 4
CONTRACT AWARD
FILTERS NO.4,5,6 SHUT DOWN
DEMOLITION ROCK MEDIA REMOVAL ROTARY DISTRIBUTORS DISMANTLED
EFFLUENT CHANNEL COVER EFFLUENT COLLECTION BOXES AIR DUCTS LOWER RING BEAM CENTER COLUMN FOUNDATION
MEDIA SUPPORT SYSTEM WALL MASONRY AND UPPER RING BEAM
WALL SEALER
FILTER 4 COMPLETE
PLASTIC MEDIA INSTALLATION
FILTER RETURN BOX 36" RCP FANS INSTALLED CENTER COLUMN PLACEMENT DISTRIBUTOR ASSEMBLY AND INSTALLATION
MAJOR EQUIPMENT ORDERED
PROCUREMENT
PUMPS DELIVERED
FILTER DISTRIBUTION STRUCTURE NO. 1
DEMOLITION 60 IN. EFFLUENT PIPE
STRUCTURAL MODIFICATIONS PIPING TO FILTERS
BACKFILLING PAINTING
PUMPS INSTALLED
CHLORINE PIPING RECONNECTED BYPASSING ENDED FILTERS NO. 1,2,3,4 STARTUP
TEMPORARY CHLORINE PIPING
BEGINNING OF BYPASS
SECONDARY SEDIMENTATION TANK DISTRIBUTION STRUCTURE
DEMOLITION
NEW STRUCTURE AND PIPING
SLUICE GATES
NOTE: CONSTRUCTION ELEMENTS FOR TRICKLING FILTERS NO. 5 AND 6 NOT SHOWN.
TRICKLING FILTERS NO. 1 2, 3
ROTARY DISTRIBUTORS DISMANTLED
DISTRIBUTOR SALVAGE CENTER COLUMN MODIFICATIONS
DISTRIBUTORS INSTALLED AND LEVELED
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY

Figure 21. Critical path method (CPM) analysis.

Also, the modifications to filter distribution structure No. 1 required essentially the whole 90-day bypass period to complete and thus represents the critical path for this period.

The 90-day bypass period determined scheduling of modifications to the two distribution structures and the repairs to the rock media filters. All major modifications to filter distribution structure No. 1 were completed within the bypass period and prior to the arrival of the pumps. Repairs to the rock media filters and modifications to the secondary clarifier distribution structure had to be completed within the bypass period and prior to startup.

Temporary chlorine piping had to be installed before bypassing to allow disinfection of primary effluent prior to discharge to the ponds. This procedure required only a few days and was most conveniently accomplished just before bypassing began. The temporary piping had to be removed and the original system reconnected just prior to startup.

Major Construction Items

Construction activities for each major construction item are discussed briefly in this subsection, along with problems encountered and adjustments made. The timing of the activities which were required to put the four filters back into operation has been previously itemized in Figure 21. Most of the additional work involved the conversion of filters No. 5 and 6 to plastic media. The construction sequence for these filters was nearly the same as that shown for filter No. 4 in Figure 21.

Plastic Media Filter Conversion--

Filters No. 4, 5, and 6 were shut down in January 1973 for modifications. Removal of the rock media and dismantling of the rotary distributors were begun immediately on all three filters. Modifications were made first to filter No. 4, since it had to be in operation first. Structural work on filter No. 4 was approximately halfway complete before construction was begun on filters No. 5 and 6.

Some demolition of the existing filter walls and floors was necessary to allow for new structures. Holes were broken in the bottom of the effluent collection channels for the new effluent collection boxes. A portion of the filter wall was removed in four places on each filter for the air inlet ducts. On filters No. 5 and 6, a portion of the floor was removed in order to put in the foul air ducts leading from the headworks. A 4.6-m (15-ft) square area was broken out of each filter floor to allow excavation for the new center column foundations. Excavation of a vertical wall is normally difficult because of the possibility of a cave-in; the ground under the filters was unexpectedly stable. The excavation pit was shored for safety and compliance with safety codes. Excavation was also required for the new effluent collection boxes.

The first concrete pour was for the effluent channel cover and was followed by those for the lower ring beam on the filter wall and the air ducts. The lower ring beam was poured in two sections. Filter No. 6 is shown at this stage of construction in Figure 22. The center column support, the lower ring beam, the effluent channel cover, and three of the air ducts are complete.

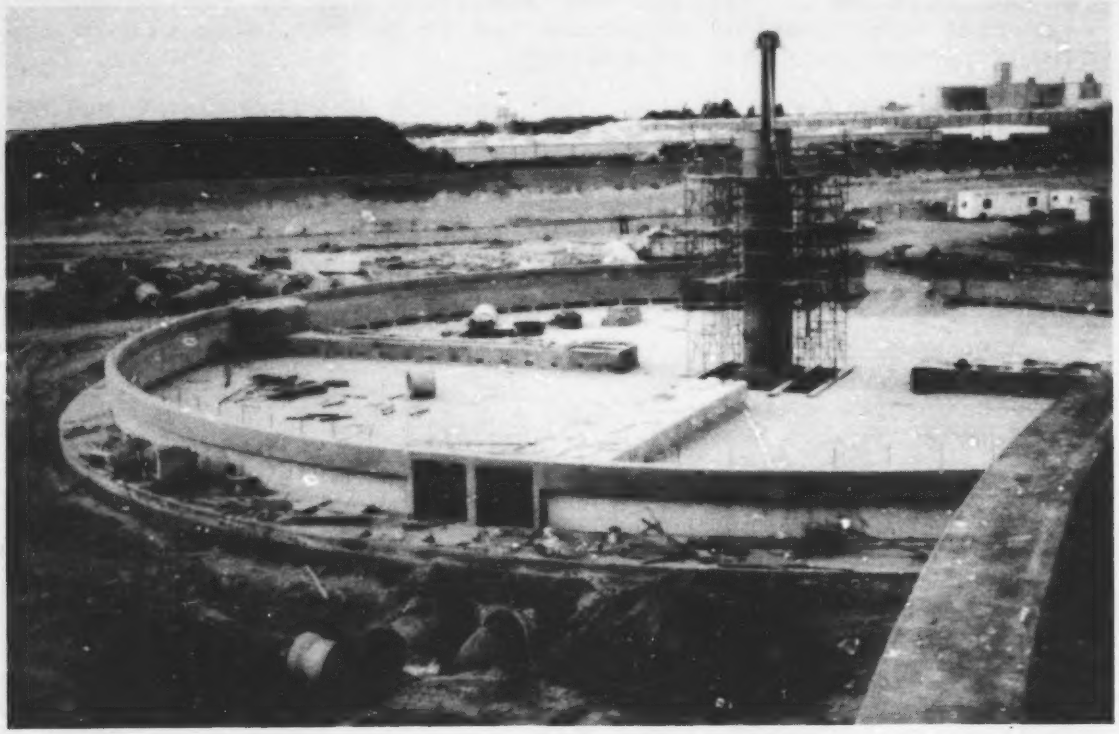


Figure 22. Early phase of filter conversion. Shown are the center column, influent distributor column, air ducts, lower ring beam, and fan housing for filter No. 4.

The piers for the media support system were installed by quadrant; variations in the floor elevation of up to 8 cm (3 in.) made modifications in pier heights necessary. The piers were designed to be a nominal 3-1/2 concrete blocks high; this design posed a problem in that concrete blocks had to be cut to allow for floor elevation variations. Piers of equal height were installed and then cut to compensate for the variations. This proved to be a time-consuming procedure. Media support channels were measured and precut, then set on the piers with a crane. The quality of the precast channels was poor; depth variations were excessive, and many had not been cut to the right lengths.

During construction, it was found that hydrogen sulfide had caused deterioration of existing filter influent lines on filters No. 5 and 6 and portions of these lines had to be repaired. Flexible joints were installed between the influent lines and the new center column foundation to allow for differential settling.

After the filter walls were constructed, a sealer was applied to the inside of the walls. The coal tar epoxy sealer used on filter No. 4 did not seal properly. A polyurethane sealer was used instead on filters No. 5 and 6. The center columns and the rotary distributor were installed in filters No. 5 and 6 before the plastic media; the filters were then operated without the media to test the sealer (Figure 23). The polyurethane sealed the walls satisfactorily.

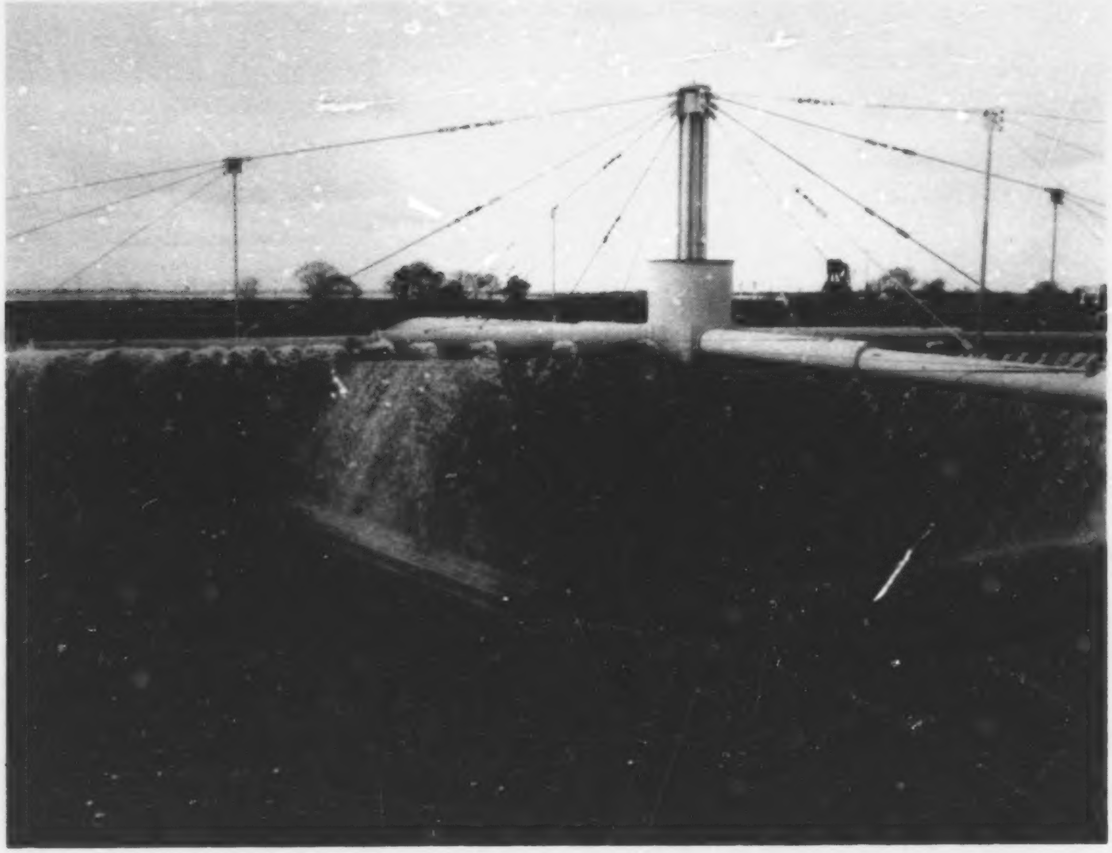


Figure 23. Operation of distributor prior to media installation. After leakage occurred through walls of filter No. 4, a different sealer was used for the inside walls of filters No. 5 and 6. These filters were then tested for leaks prior to media installation.

Excavation for the 0.91-m (36-in.) effluent collection pipes and the filter return box was begun, but not completed, prior to media installation at each filter. The filter was then turned over to the Lomar Corporation for installation of the plastic media. The first layer of media in filter No. 5 is shown in Figure 24. The conveyor belt which lifted the media blocks to the top of the filter is shown in Figure 25. Media installation required approximately 6 wk for filter No. 4. When media installation was nearly complete, work resumed on the effluent collection system. After the effluent collection pipes were laid and the trenches backfilled, the housings for the filter fans were formed and poured. The rotary distributors were leveled after the media was in place.

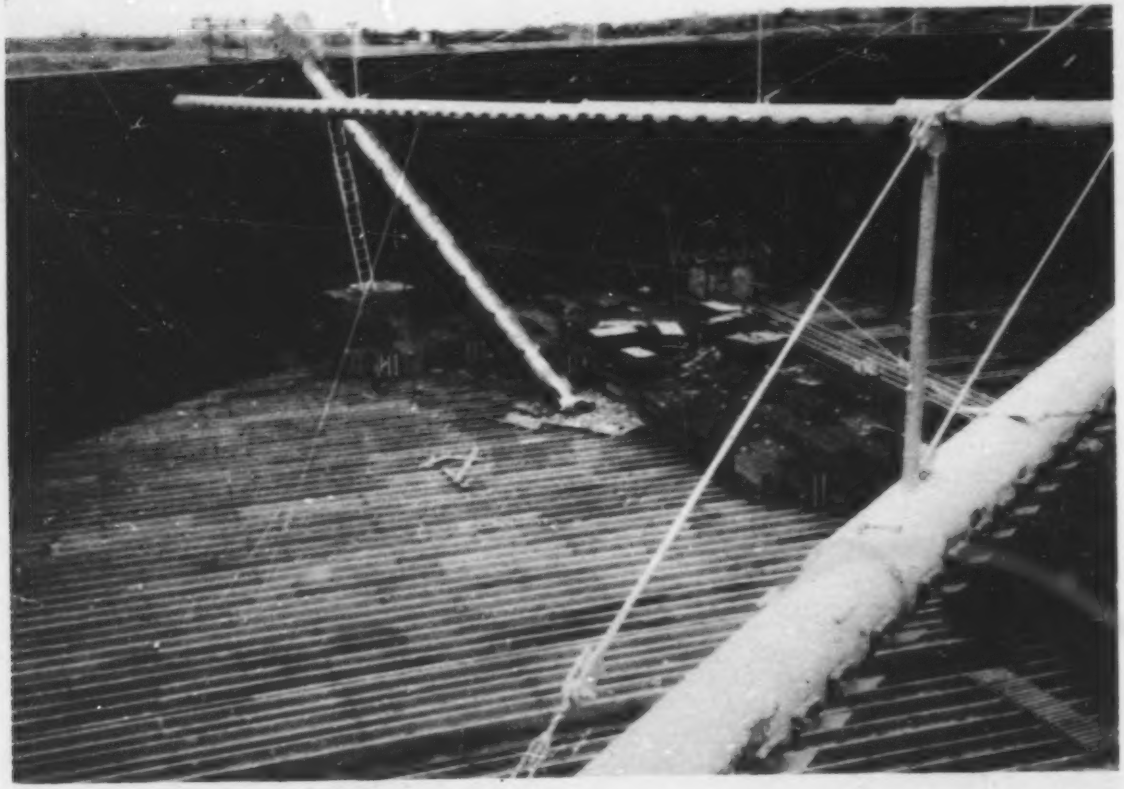


Figure 24. Plastic media installation. First layer of media being installed for filter No. 5.

Filter No. 4 was started up before it was entirely complete to receive canning season loadings. A portion of the effluent collection system and the electrical connections to the fans were completed after startup.

Filter Distribution Structure No. 1 and Piping--

Excavation around the trickling filter distribution structure and for the new 1.52-m (60-in.) effluent pipe began in April 1973. Secondary facilities were bypassed (the beginning of the 90-day period) to allow demolition of one wall of the structure and replacement of piping. A leaky valve on one pipe from the primary sedimentation tank delayed demolition several days.

Laying of the 1.52-m (60-in.) reinforced concrete pipe to the secondary sedimentation tank distribution structure was the first major task, followed by demolition of the western wall of the structure. The original 0.91-m (36-in.) effluent pipes from filters No. 4, 5, and 6 were removed and replaced with 1.22-m (48-in.) pipes. The existing 0.91-m (36-in.) filter supply pipes were partially removed and replaced with new 0.91-m (36-in.) pipes which routed influent through the supply pumps.

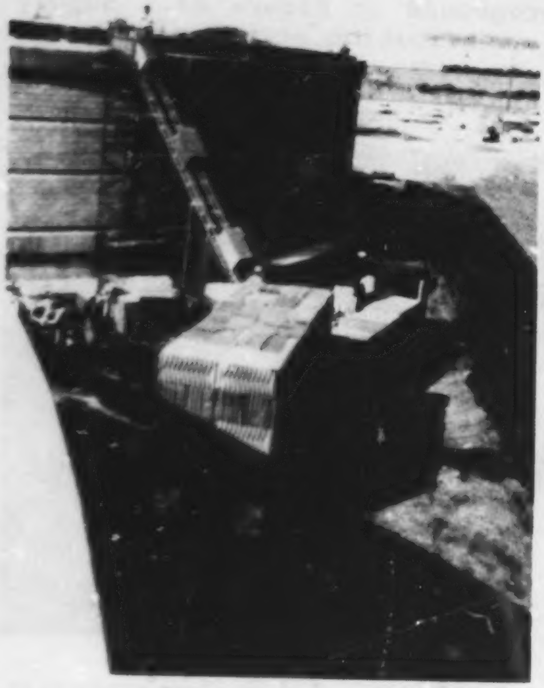


Figure 25. Plastic media conveyor. Media modules were fabricated near the site, delivered by truck, and conveyed to the top of the filter wall.

Forming and pouring the new chamber walls and the collars for pipe connections constituted most of the work on the filter distribution structure. The south wall of the structure with the concrete forms in place is shown in Figure 26. The concrete work for the complicated structure (Figure 19, Section 5) was completed in a single pour. For the most part, work proceeded steadily and without problems or adjustments. Backfilling of excavated areas and painting of the structure was begun in early July.

The supply pump for filter No. 4 was installed first, during the second week in July. This was followed by reinstallation of the four original recirculation pumps which were removed before modifications were begun. The electrical connections to the original recirculation pumps were completed while filters No. 1, 2, and 3 were started up. The two new recirculation pumps were electrically connected after the rock media filters were put on line and just prior to startup of filter No. 4. Supply pumps No. 5 and 6 were installed in August; they are shown in the foreground in Figure 27. Supply pump No. 4 is to the left of the distribution structure; one of the new recirculation pumps can be seen on the far right end of the structure.

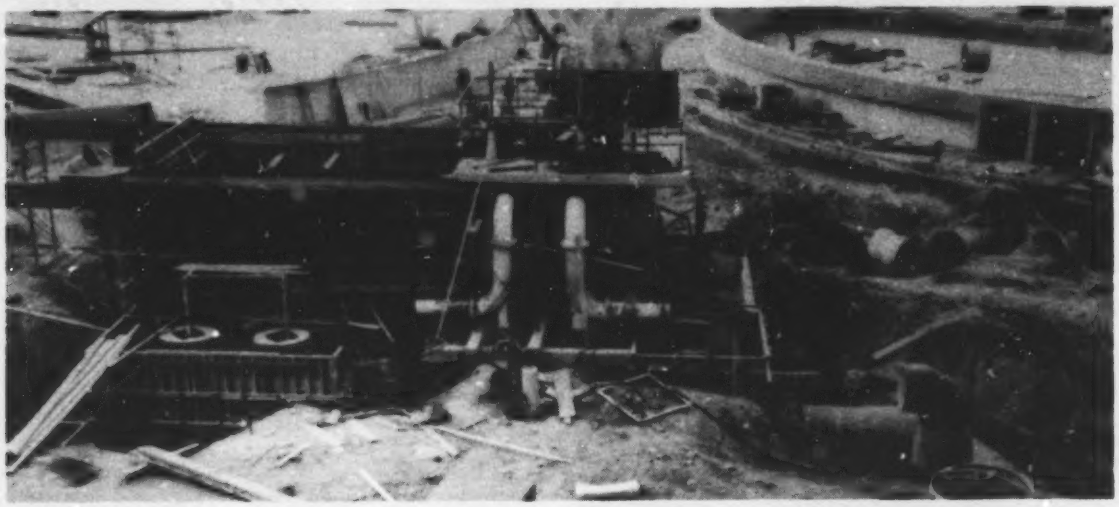


Figure 26. Trickling filter distribution structure. New portion of structure is to the left.

A leak was discovered in an original line between trickling filter distribution stuctures No. 1 and 2 after startup. The area around the pipe was excavated and a collar was formed around the leaky pipe.

Secondary Sedimentation Tank Distribution Structure--

Excavation for the secondary sedimentation tank distribution structure began in early May. The original structure was entirely demolished, and a small, submersible electric pump was installed in the excavated area to pump out groundwater. The entire structure was located 53 cm (1 ft-9 in.) east of the plan location to avoid an existing bypass line. New collars were formed on existing pipes for connection to the new structure. A portion of the pipe to a planned-for fifth sedimentation tank was laid and capped. The east side of the structure is shown in Figure 28. In the center foreground is a section of the new 1.52-m (60-in.) influent pipe; to the right of the new pipe is the old 1.52-m (60-in.) pipe.

The structure was essentially complete by the end of June. Installation of the sluice gates and backfilling around the structure were done the first week in July. Painting was completed just before the end of bypassing.

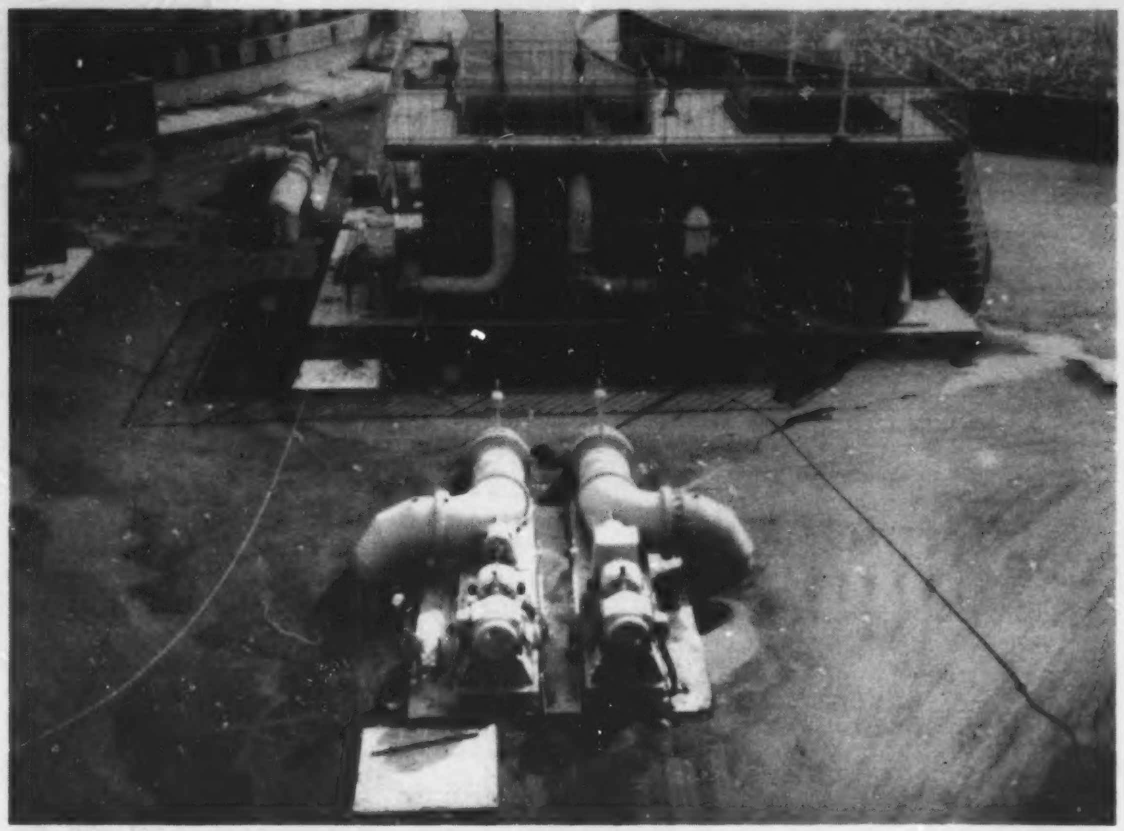


Figure 27. Supply and recirculation pumps. Supply pumps for filters No. 5 and 6 are in foreground; supply pump for filter No. 4 is beyond distribution structure to the left. One of the new recirculation pumps is near the right side of the distribution structure.

Repairs to Rock Media Filters--

During the bypass period required for modifications to the distribution structures, repairs were made on the three rock media filters (filters No. 1, 2, and 3). The major repair was to the rotary distributors. Portions of the original distributors from filters No. 4, 5, and 6 were salvaged and combined to make two good ones for filters No. 1 and 2. The distributor for filter No. 3 was left in place; it was sandblasted and repainted. Distributor columns from filters No. 5 and 6 were installed in filters No. 1 and 2; repair of the center piers which support the distributor columns was necessary.

The salvaged distributors were sandblasted, and corroded parts were replaced. An organic zinc primer coat was applied prior to four coats of paint. Center column bearings were repaired or replaced. The distributors for filters No. 1 and 2 were then installed and leveled. The CPM chart (Figure 21) shows the timing of the repair operations relative to work on the other structures. Flow was readmitted to the filters as soon as the distributors were operating. Minor repairs and adjustments were made after bypassing was discontinued.

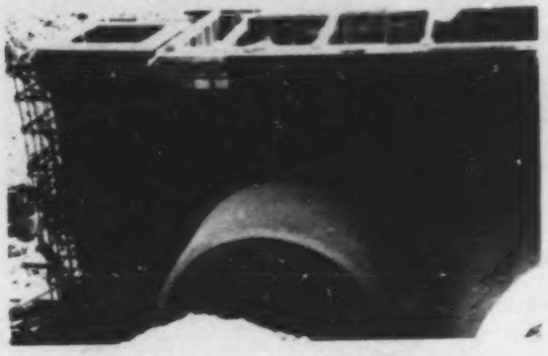


Figure 28. Secondary sedimentation tank distribution structure. New filter effluent line is at center; old line is at right.

Electrical Modifications--

Electrical work began in mid-March and continued steadily throughout the contract. Some difficulty was experienced in delivery of equipment. Delivery of a critical high-voltage cable was delayed; however, the local electric utility company, Pacific Gas and Electric, released a similar cable it had ordered to help avoid construction delays.

The ducts and conduits were laid while electricians worked on operations building modifications. A new main switch station was installed in June. Electrical activities intensified as the filter distribution structure neared completion. Electrical hookups to pumps and the trickling filter substation were part of the critical path just prior to startup (see Figure 21).

Construction Progress

An unusual amount of rain during the months of January, February, and March 1973 caused construction delays. Regular overtime hours were authorized in February to compensate for time lost in January. Exceptionally heavy rains in February and March resulted in a 10-working-day extension of the required completion time for filter No. 4. Operations continued at a slower-than-normal pace. For example, masonry for the filter walls could not be placed during rain. The contractor ordered extra material for concrete forms in order to pour several structures concurrently rather than consecutively as planned.

Construction progress is illustrated in Figure 29. Construction progress payments were used as an indicator of the percent of project completion. When filter No. 4 went into operation in July, approximately 70 percent of constuction was complete; by November 1973, 99.7 percent of construction was complete. Correction of deficiency items continued through 1974 and into 1975.

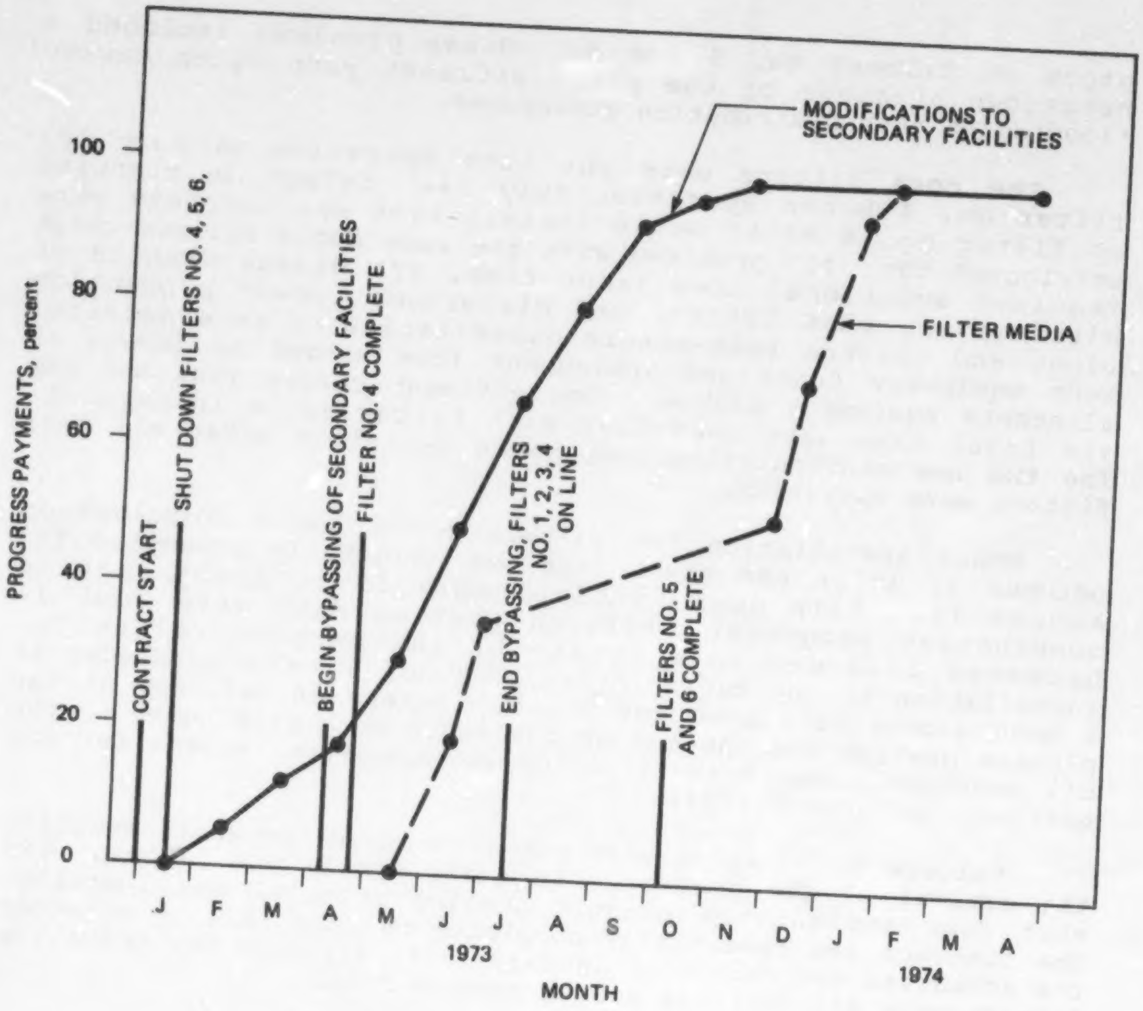


Figure 29. Construction progress.

Filter No. 4 had been scheduled to be structurally complete by April 15, 1973; plastic media was to be installed between April 15 and June 15. Filter No. 4 was to be on line by June 30 and filters No. 5 and 6 on line by September 15.

Filter No. 4 was structurally complete except for the effluent collection pipes on April 27, 12 days after the scheduled date. The filter-media contractor moved in on May 2. There were some delays in plastic media installation due to slow material deliveries, but filter-media installation was completed by June 15, the original scheduled date.

Unexpected deterioration (wall leaks) of portions of the filter distribution structure required extra work for the contractor as did deterioration of the 0.91-m (36-in.) influent pipes to filters No. 5 and 6. Other problems included a breakdown stoppage of the plant effluent pump which caused flooding of both distribution structures.

The rock filters were put into operation on July 17; filter No. 4 began operation July 24. Delays in starting up filter No. 4 after media installation was complete were attributed to: (1) problems with the rock media filters which required additional crew labor time, (2) miscalculation of electrician, pipe fitter, and millwright crews' production time, and (3) the last-minute cancellation of an electrical test equipment order and subsequent time needed to locate an alternate equipment source. One effluent return line and the air inlet fans were installed with filter No. 4 in service. The two new recirculation pumps were installed after all four filters were operating.

Media installation for filters No. 5 and 6 commenced on October 3, 1973; the start date was originally scheduled for August 15. Rain began in September 1973, again slowing constuction progress. Fifteen working days were lost in December 1973 due to a strike by the carpenters' union. Installation of the media for filters No. 5 and 6 proceeded at a much slower pace than for No. 4. Delays in delivery of the plastic grating for the top of the media were attributed to the oil shortage. Media installation was complete, except for the grating, in January 1974.

Filters No. 5 and 6 were put into operation while awaiting the arrival of the grating. In early April, the filters were shut down and the new plastic grating material was installed The contract was essentially completed in July 1974, 6 mo after the scheduled completion of January 1974, although the trickling filters were all operable during this period.

STARTUP

The three rock media filters and one plastic media filter were operational in time for the 1973 canning season as required. Filters No. 5 and 6 were completed and were operational by January 1974. Operational problems encountered during startup were leakage through the walls of filter No. 4, overheating of one of the new recirculation pumps, and slamming of the check valves in the new recirculation pumps.

Leakage through the walls on filter No. 4 was noticed immediately after startup. As indicated above, a coal tar epoxy had been used as a sealer on the inside walls and, for the reasons discussed previously, allowed wastewater to leak through the filter walls. While resulting in an unsightly appearance and causing aquatic growths on the outside walls, it was determined that no structural damage would result.

Because filters No. 5 and 6 had not been completed at this time, it was possible to use another method of sealing their walls. The polyurethane sealer used for these two filters provided a significant improvement, although a few minor leaks did occur.

The occurrence of the leaks points out the necessity of taking adequate precautions against such problems when open-block construction is used. Suggested techniques for accomplishing this are presented in Section 8.

Overheating of the new filter recirculation pump was traced to an unexpectedly high pumping head, coupled with marginally sized electric wires leading from the control building. During subsequent plant modification (undertaken in 1977), the pumping head was reduced by installing new secondary clarifier effluent troughs at a higher elevation than the old ones. This caused the water level in the outer box of the filter recirculation sump to be raised and reduced the head on the pumps.

The new filter recirculation pumps were installed to provide discharge below the water line in the inner chamber of the distribution structure. This necessitated installation of check valves to prevent backflow into the outer chamber when the pumps are not operating. Severe slamming resulted when the pumps were shut off, however.

SECTION 7

OPERATION AND PERFORMANCE

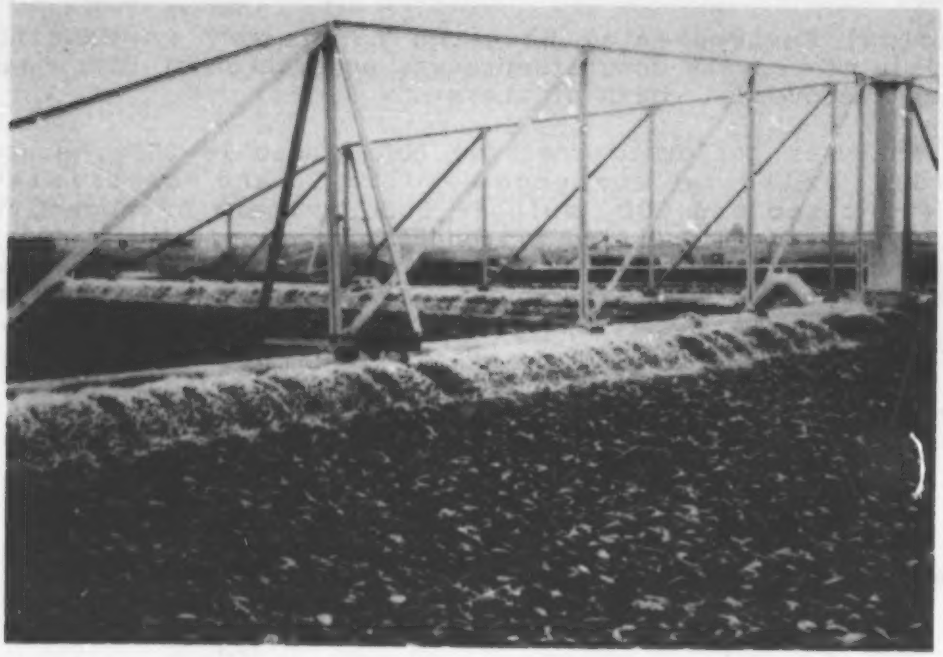
With completion of the secondary treatment modifications in December 1973, the city began full-time operation of the plastic media biofilters. Normally, the plastic media filters and the three remaining rock filters (Figure 30) are operated in parallel from the common distribution structure as described in Section 5. A disadvantage to this method of operation is that it is impossible to evaluate the performance of the plastic media alone because of the mixing of the effluent from each type prior to recirculation.

Because the plant's capacity had not been reached and because the treatment contribution of the rock filters was minimal, the city agreed to shut down the three rock filters for a 1-yr period while a special sampling program was undertaken in conjunction with this study. The purpose of the sampling program was to document the performance of the plastic media filters over the entire range of conditions encountered at Stockton, including the canning and noncanning seasons and the transition periods between them.

SPECIAL SAMPLING AND ANALYTICAL PROGRAM

A complete description of the sampling program and the sampling and analytical techniques employed is presented in Appendix D. Briefly, sampling was begun on March 15, 1976, and completed on March 16, 1977. Four sampling points were used: raw wastewater (primary influent), primary effluent, trickling filter effluent (unsettled), and secondary effluent. Four portable, refrigerated, automatic composite samplers were used. Sampling was triggered by a 24-hr timer which had been calibrated to provide a simulated diurnal flow variation by sampling at varying frequencies throughout the day. This provided samples which were reasonably close to being flow-proportioned.

Samples were taken 3 days per week, beginning each Monday, Tuesday, and Wednesday morning at approximately 9:00 a.m. and collected on the following day. The samples were packed in ice and shipped to Brown and Caldwell's laboratory facilities in San Francisco. The samples were then split, and portions of them were preserved and shipped via air freight to EPA's



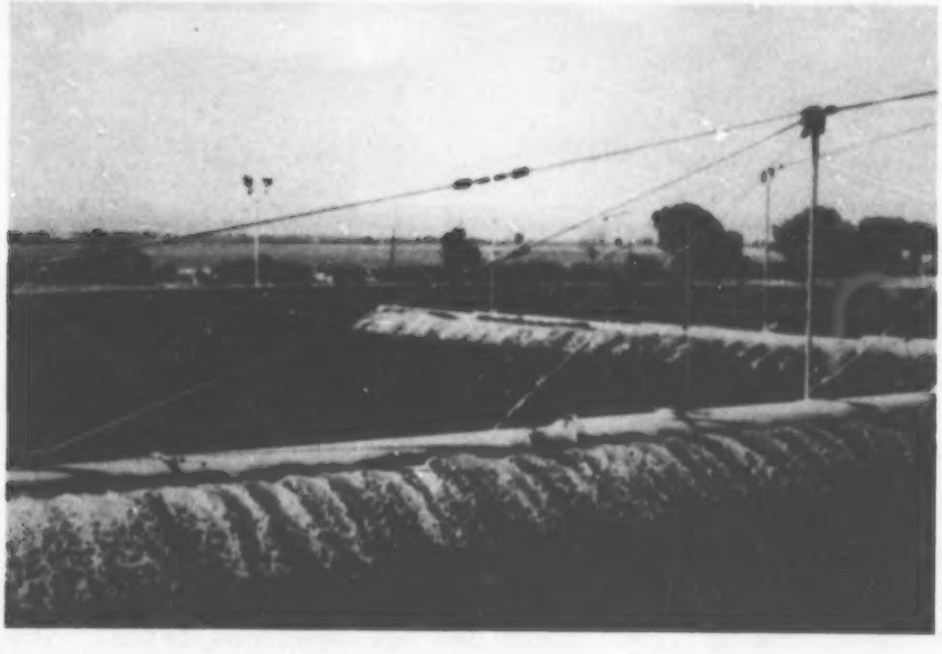


Figure 30. Plastic media and rock media trickling filters at Stockton. The three original rock filters are normally operated in parallel with the three new plastic media filters, but they were shut down during the special 1-year sampling program for this study.

Municipal Environmental Research Laboratory in Cincinnati. Analysis of certain constituents was undertaken at Cincinnati to reduce the overall costs of the study.

Analyses performed included BOD_5, soluble BOD_5, suspended solids, volatile suspended solids, and alkalinity at San Francisco and COD, soluble COD, ammonia nitrogen, total Kjeldahl nitrogen, nitrite nitrogen, nitrate nitrogen, and total phosphorus at Cincinnati. City laboratory and operation records were used to obtain values of wastewater flow, temperature, dissolved oxygen level, and pH. A complete listing of analyses is presented in Table 12. Data obtained during the study are presented on a daily basis in Tables E-1 through E-3 in Appendix E. Selected data are presented below as necessary to illustrate specific aspects of plant operation and performance.

TABLE 12. PARAMETERS MEASURED DURING SAMPLING PROGRAM

Parameter	Sampling location			
	Raw influent	Primary effluent	Biofilter effluent	Secondary effluent
Flow[a]	X			
Trickling filter recirculation flow[a]			X	
BOD_5[b]	X	X		X
Soluble BOD_5[b]		X[c]		X[c]
COD[d]	X	X	X	X
Soluble COD[d]	X	X	X	X
Suspended solids[b]	X	X	X	X
Volatile suspended solids[b]	X	X	X	X
Total phosphorus[d]	X	X		X
Total Kjeldahl nitrogen[d]	X	X		X
Ammonia nitrogen[d]	X	X		X
Nitrite nitrogen[d]	X	X		X
Nitrate nitrogen[d]	X	X		X
Alkalinity[b]		X[c]		X
Temperature[a]		X	X	
pH[a]		X	X	
Dissolved oxygen[a]			X	

[a] Measured or analyzed by plant staff.

[b] Analyzed by Brown and Caldwell.

[c] Measured once per week.

[d] Analyzed by EPA, Cincinnati.

At the time the sampling program was undertaken, several elements of the upgraded plant had not been completed. The most significant of these was the tertiary algae removal facility, consisting of dissolved air flotation, dual-media filtration, and chlorination-dechlorination. During the sampling program, secondary effluent was treated in the oxidation ponds and then discharged to the San Joaquin River.

Other portions of the upgraded plant described in Section 4 which had not been completed at the time the sampling program was initiated included construction of a new river crossing, provision of vacuum filtration for sludge dewatering, and installation of new secondary clarifier effluent collection troughs. The last item is of interest because of the poor hydraulic distribution among the four secondary clarifiers and within each clarifier. Poor hydraulic distribution in the secondary clarifiers had been a problem for several years. The existence of the large oxidation ponds eliminated concern over this poor distribution because of the ponds' large treatment capacity. Secondary effluent data presented in this report, however, might have exhibited lower contaminant levels if the new facilities had been completed at the time of the sampling program.

An important construction item affecting data evaluation during the sampling program involved the expansion and modification of the headworks area. This included addition of three new grit removal channels and Parshall flumes and rehabilitation of the three existing channels and flumes. As a result of this construction, adequate plant flow data are not available for the first 2 mo of the study. Based on available data from prior and subsequent periods, the flow during this time has been estimated at 61,000 m^3/day (16.0 mgd). This value is used throughout this report for the period from March 15 through May 19, 1976.

PLANT OPERATION DURING SAMPLING PROGRAM

Several operational changes occurred during the sampling program which affected data collection. Various units were out of service for a portion of the sampling period; one of the plastic media biofilters was shut down for 2 mo at the beginning of the program, and one or more of the primary and secondary clarifiers were kept out of service during the noncanning season.

Some changes were initiated by the plant staff in response to problems which occurred. Shortly after the beginning of the canning season, it was determined that the primary clarifier sludge removal equipment was unable to handle the large quantity of solids entering the plant and that significant carryover of settleable solids to the secondary treatment system was occurring (Figure 31). Solids removed from the secondary clarifier are normally recycled back to the headworks, and the result was a gradual buildup of solids in the primary and secondary treatment systems. The plant staff solved the problem by constructing a temporary pipeline and pumping secondary sludge from the secondary clarifiers directly to the sludge lagoons. This was continued until the end of the canning season.

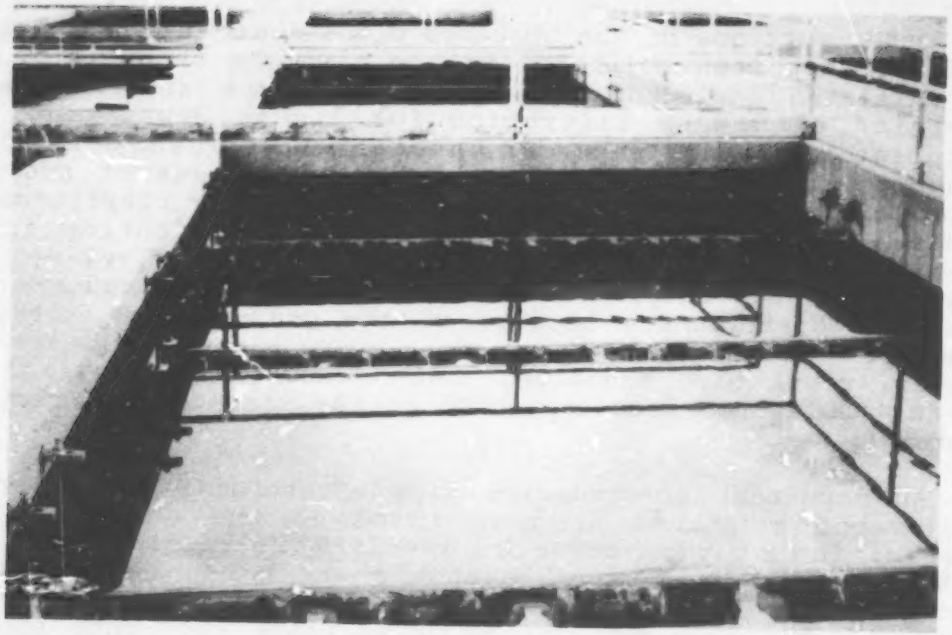


Figure 31. Stockton primary clarifiers. Heavy solids loading during the 1976 canning season overloaded sludge removal system.

Several operational changes were implemented in response to data developed during the sampling program. These relate to the total hydraulic loading (influent plus recycle) on the filters and to the air flow provided by the forced draft ventilation system. As discussed below, ammonia nitrogen removal during the first portion of the sampling program prior to the start of the canning season (March 15 to July 31, 1976) was inconsistent. Among the possible explanations were inadequate total hydraulic loading to achieve effective media wetting and inadequate air supply; therefore, these operating parameters were modified during the latter portion of the sampling program in an attempt to obtain improved performance.

Most manufacturers of synthetic trickling filter media recommend a minimum total hydraulic loading to ensure complete wetting of the media surface, which allows the media to be fully effective in biological treatment. B. F. Goodrich recommends a minimum value of 0.031 $m^3/min/m^2$ (0.75 gpm/ft^2) for Vinyl Core (8). Plant records indicated that the total hydraulic loading being applied at Stockton was approximately 0.024 $m^3/min/m^2$ (0.6 gpm/ft^2); the variable-speed supply pumps were being operated at a motor speed of about 1,500 rpm. It was, therefore, requested that the city increase the trickling filter supply flow (and thus the recirculation flow) to the recommended minimum wetting rate. The city readily agreed, and in mid-October the change was made; the total hydraulic loading was increased to approximately 0.031 $m^3/min/m^2$ (0.75 gpm/ft^2).

At the same time that the hydraulic loading was increased, the air supply to the biofilters was also increased. Grab sample dissolved oxygen concentrations of unsettled biofilter effluent are measured each day by the laboratory staff. Review of plant records for the period in question showed the concentrations measured to be high, usually above 5 mg/l, even though very few fans, two or fewer (of eight per filter) were being operated. It was hypothesized that the wastewater dissolved oxygen concentration was being raised when the water drops fell from the media to the floor and were transported to the effluent collection boxes where the grab samples were taken. Therefore, the number of operating fans was increased to four per filter.

As will be discussed in the subsection on nitrification performance, nitrification efficiency increased significantly subsequent to these changes, although it cannot be certain which (if either) of the operational changes influenced performance. This question will be discussed again below.

Another change in fan operation was made in January 1977 just prior to the end of the study. The change was made in an attempt to reduce suspended solids levels in the secondary effluent during the noncanning season. Shortly after the plastic media biofilters had been put into operation, the plant staff began to notice that during portions of the day, high concentrations of finely dispersed solids were noticeable near the surface of the secondary clarifiers. Qualitative dye tracer tests undertaken by the staff showed dye breaking through and appearing in the secondary clarifier effluent in less than 5 min. This condition was indicative of severe short-circuiting.

Observations made during the course of this study, and which are described below under the subsection on performance, led to the tentative conclusion that the problem resulted from temperature/density gradients being set up in the secondary clarifiers by the diurnal fluctuations in ambient air temperature and wastewater flow. During the night, low air temperatures and low wastewater flows result in a large wastewater temperature drop through the biofilter, and relatively cold water would thus enter the clarifiers. In the morning, the air temperature and wastewater flow would increase, causing the temperature of the biofilter effluent to increase. This warmer, less dense water would then rise to the surface and move over the cold, more dense water present in the clarifiers. The low hydraulic loadings and high air flows required for nitrification would magnify the problem. It was expected that the layering phenomenon would be quite unstable and could be eliminated by turbulence within several hours.

Thermodynamics calculations indicated that daytime and nighttime temperature drops through the biofilters could be made nearly equal by operating six fans during the day (from 8:00 a.m. to 8:00 p.m.) and two fans at night. The fans were operated in this manner for the last several weeks of the program, and a significant (though short-term) reduction in secondary effluent suspended solids concentrations resulted.

Summarized in Figure 32 are the major changes in plant operating parameters discussed above. Shown on the figure are primary and secondary clarifier operations, secondary sludge pumping, hydraulic loading, and fan operation.

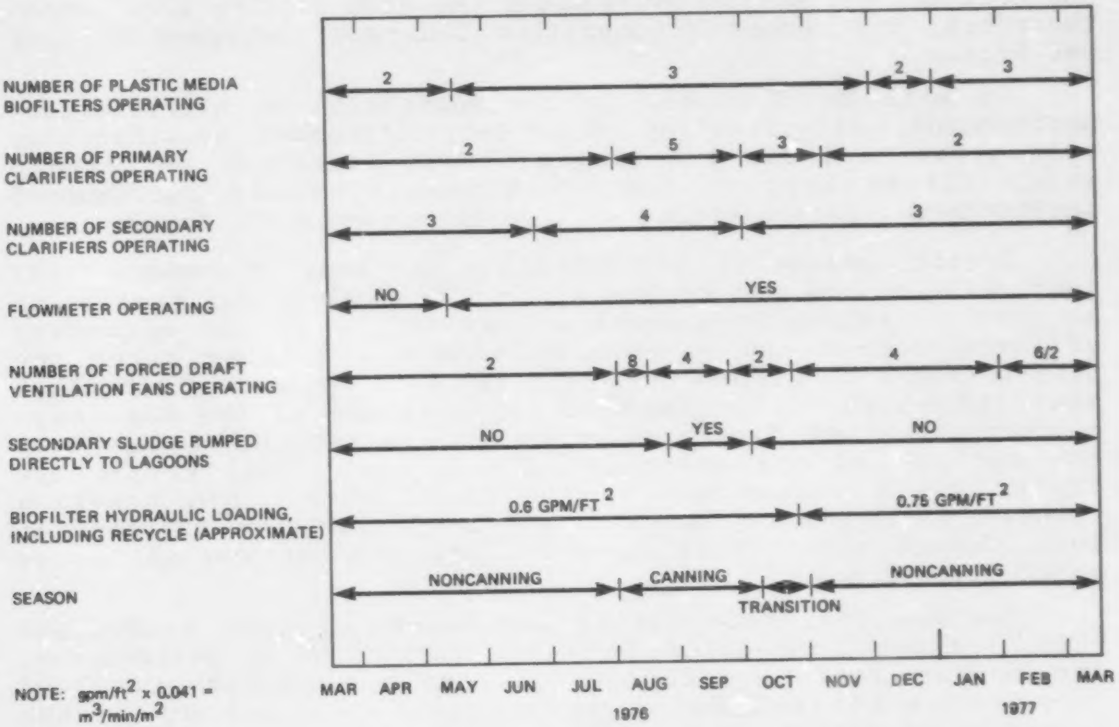


Figure 32. Changes in plant operating parameters during sampling program.

PERFORMANCE

Prior to discussing specific aspects of secondary treatment performance, a summary of plant performance is presented here to give an overview of the Stockton plant operations during 1976-1977. Monthly averages of major constituent concentrations are presented in Tables 13 through 17. Included are total and soluble BOD_5, total COD, total and volatile suspended solids, total phosphorus, total Kjeldahl nitrogen, ammonia nitrogen, secondary effluent nitrate nitrogen, alkalinity, wastewater temperature, dissolved oxygen, and pH. Daily values for these and other data are listed in Appendix E.

TABLE 13. MONTHLY AVERAGES FOR FLOW, BOD_5, AND SOLUBLE BOD_5

Month, 1976-77	Flow, mgd[a]	BOD_5, mg/l			Soluble BOD_5, mg/l	
		Raw Influent	Primary Effluent	Secondary Effluent	Primary Effluent	Secondary Effluent
March	16[b]	290	170	28	75	18
April	16[b]	250	150	16	52	6
May	19[b]	260	130	21	48	10
June	18	270	140	27	66	12
July	18	300	150	29	60	16
August	39	630	320	130	210	93
September	35	420	240	59	180	26
October	19	380	210	33	110	15
November	17	330	220	24	120	13
December	17	430	230	19	97	10
January	18	370	220	15	130	7
February	18	380	180	15	85	6
March	17	360	190	14	54	7

[a] mgd x 3,785 = m^3/day.

[b] Flow meter not working. Flow estimated at 60,000 m^3/day (16.0 mgd) from 3/15/76 to 5/19/76.

TABLE 14. MONTHLY AVERAGES FOR SUSPENDED SOLIDS AND VOLATILE SUSPENDED SOLIDS

Month, 1976-77	Suspended solids, mg/l				Volatile suspended solids, mg/l			
	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.
March	360	230	140	37	280	150	90	28
April	280	140	140	27	230	130	110	22
May	320	140	160	25	230	110	110	19
June	320	120	140	42	230	91	90	31
July	450	140	150	23	290	120	120	19
August	740	220	220	51	480	190	190	47
September	580	140	150	44	370	120	120	38
October	520	150	160	47	370	120	130	43
November	390	130	140	36	310	120	120	32
December	400	140	140	25	320	120	110	23
January	470	120	140	30	370	96	100	24
February	410	170	160	19	320	140	120	17
March	410	240	150	26	310	180	120	18

TABLE 15. MONTHLY AVERAGES FOR TOTAL PHOSPHORUS AND TOTAL COD

Month, 1976-77	Total phosphorus, mg/l as P			Total COD, mg/l			
	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.
March	7.5	6.6	5.8	650	380	220	110
April	7.2	6.6	6.1	590	360	220	110
May	7.3	6.3	5.5	570	320	210	120
June	6.7	6.8	6.3	540	260	160	90
July	7.7	6.0	5.6	610	270	180	100
August	6.0	3.3	2.1	1,040	530	360	260
September	6.1	3.3	2.7	900	450	260	200
October	8.2	6.1	5.1	820	390	220	150
November	11	9.4	6.5	690	350	190	110
December	11	8.4	7.5	810	390	190	100
January	9.9	6.7	6.3	810	350	200	100
February	9.3	7.7	6.6	780	310	230	110
March	8.6	7.4[a]	6.8	690	370[a]	290	90

[a] Data available for 1 day only.

TABLE 16. MONTHLY AVERAGES FOR TOTAL KJELDAHL NITROGEN, AMMONIA NITROGEN, AND SECONDARY EFFLUENT NITRATE NITROGEN

Month, 1976-77	Total Kjeldahl nitrogen, mg/l			Ammonia nitrogen, mg/l			Nitrate nitrogen, mg/l
	Raw Influent	Primary Effluent	Secondary Effluent	Raw Influent	Primary Effluent	Secondary Effluent	Secondary Effluent
March	30	27	16	17	14	9.4	0.3
April	24	24	9.2	16	15	4.7	2.7
May	28	25	10	13	15	5.8	5.0
June	23	21	9.0	15	16	4.0	1.8
July	29	24	11	18	15	5.0	0.8
August	34	41	31	11	22	16	<0.1
September	29	27	19	12	14	8.4	<0.1
October	40	31	16	16	17	8.0	0.4
November	36	32	10	20	20	4.2	1.1
December	46	38	14	25	23	4.6	0.8
January	55	38	16	26	23	2.0	2.2
February	40	34	7.6	23	19	1.5	2.9
March	39	21	5.4	24	20	1.4	2.5

Several aspects of plant operation are apparent from these tables. The abrupt start of the canning season at the beginning of August is indicated by a significant increase in several raw wastewater parameters, including flow, BOD_5, suspended solids, and alkalinity. A decrease in filter effluent dissolved oxygen also reflects the increased loadings. August was the peak loading month; concentrations and flows were slightly lower in September and decreased significantly in early October as unseasonal late summer storms cut off the end of the growing season.

TABLE 17. MONTHLY AVERAGES FOR ALKALINITY, WASTEWATER TEMPERATURE, pH, AND DISSOLVED OXYGEN

Month 1976-77	Alkalinity, mg/l as $CaCO_3$		Wastewater temperature, C		pH		Dissolved oxygen, mg/l
	Prim. Effl.	Sec. Effl.	Prim. Effl.	Filter Effl.	Prim. Effl.	Filter Effl.	Filter Effl.
March	200	130	26	24	6.8	7.6	6.3
April	200	100	26	24	7.0	7.5	7.1
May	190	120	28	27	7.1	7.6	5.6
June	190	110	29	28	7.2	7.7	6.2
July	220	140	30	29	7.1	7.8	5.0
August	400	370	30	30	8.4	8.3	1.7
September	370	320	30	29	8.9	8.3	4.1
October	260	210	28	28	7.2	7.5	6.3
November	210	92	26	24	6.9	7.2	6.5
December	240	100	23	21	7.0	7.5	6.4
January	210	63	22	19	6.7	7.1	7.2
February	170	59	24	22	6.9	7.2	8.2
March	210	53	24	22	6.6	7.2	7.3

Also associated with the canning season is an increase in ammonia nitrogen level between the raw wastewater and primary effluent (Table 16). The cannery waste, principally tomatoes and peaches, is nutrient deficient, and ammonia gas is added to the waste stream to ensure that an adequate bacterial population will develop. Consequences of an insufficient supply of nutrients include growth of fungi in the biological treatment system, deterioration in performance, and odors.

Improvement in performance when the noncanning season resumed in November 1976 can be seen in the reduced concentrations of several secondary effluent constituents: BOD_5, suspended solids, and ammonia nitrogen. It is assumed that this improvement (over that experienced before the start of the canning season) is due to the operating changes discussed above.

Presented below are discussions of several specific performance parameters for the Stockton secondary treatment process: BOD_5 removal, ammonia nitrogen removal, suspended solids removal, and solids production. Following this discussion is a performance summary comparing experienced performance with design.

BOD_5 Removal

The occurrence of a 2- to 3-mo canning season at Stockton provides a wide range of organic loadings on the biofilters. Weekly loadings during the sampling program ranged from 0.16 to 1.3 $kg/m^3/day$ (10 to 80 $lb/1,000\ ft^3/day$). A graph of weekly average removals vs loadings is shown in Figure 33, and a summary of average seasonal parameters is presented in Table 18.

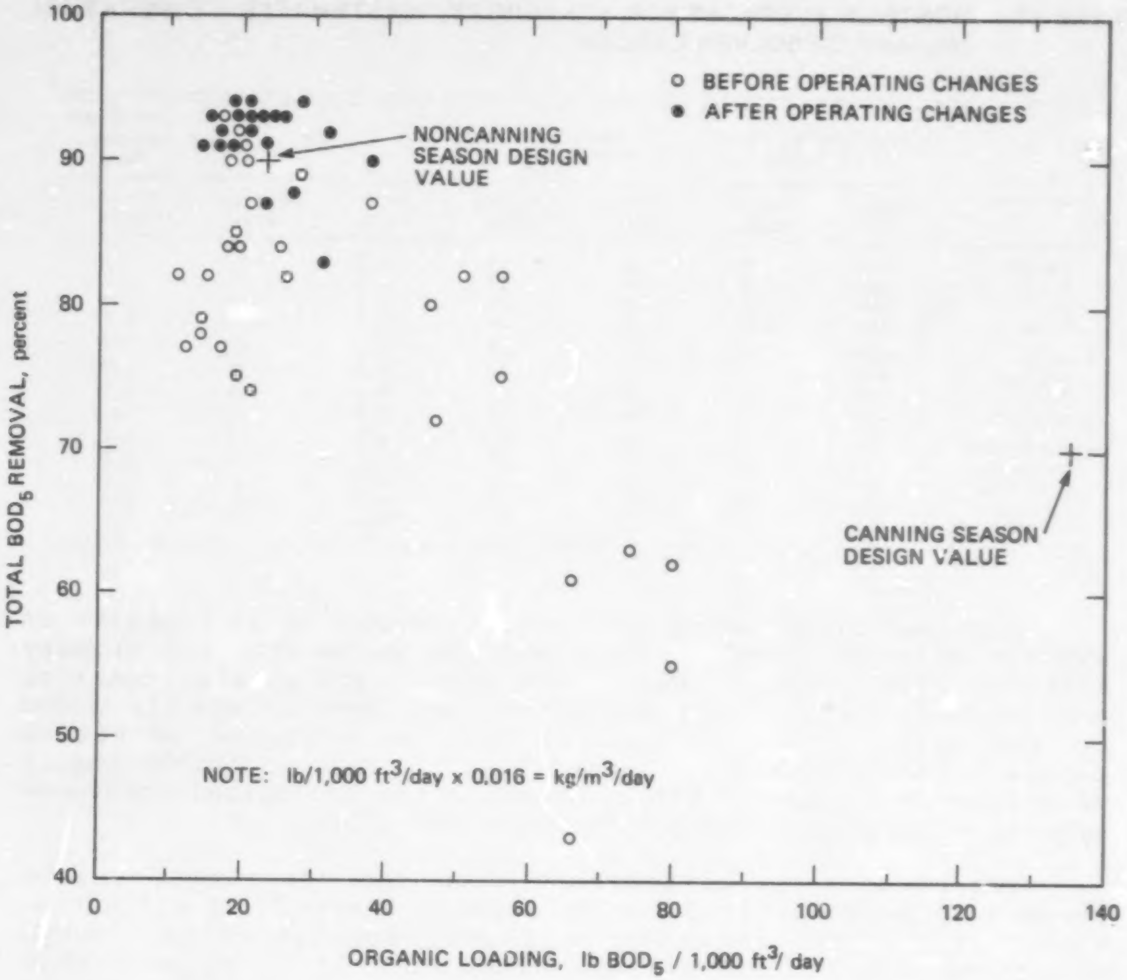


Figure 33. BOD_5 loadings and removals.

Removals were much lower than expected prior to the operational changes discussed above, averaging 84 and 80 percent for total and soluble BOD_5, respectively, in the March-July 1976 noncanning period. During the peak canning month of August, total BOD_5 removal averaged 59 percent at a loading of 0.78 kg/m^3/day (49 lb BOD_5/1,000 ft^3/day). Design removal for the canning season is, by contrast, 70 percent at a loading of 2.16 kg/m^3/day (135 lb/ 1,000 ft^3/day).

The operational changes which were instituted to improve nitrification apparently also had significant impact on BOD_5 reduction. Total BOD_5 removal increased from the previous 84 percent (March-July 1976) to 92 percent in the

November 1976-March 1977 period. The secondary effluent total BOD_5 concentration dropped from 24 to 17 mg/l. Soluble BOD_5 removal increased from 80 to 91 percent, with effluent concentrations decreasing from 12 to 9 mg/l. This improvement was obtained in conjunction with a slight increase in loading from 0.30 to 0.34 kg/m^3/day (19 to 21 lb/1,000 ft^3/day).

TABLE 18. BOD_5 REMOVAL SUMMARY

	Canning season	Noncanning season	
Parameter	August, September 1977	March through July 1976	November 1977 through March 1978
Flow, mgd[a]	37	17	17
Biofilter loading, lb/1,000 ft^3/day[b]	60	19	21
BOD_5, mg/l			
Raw influent	530	270	370
Primary effluent	280	150	210
Secondary effluent	95	24	17
BOD_5 removal, percent			
Primary treatment	47	44	43
Secondary treatment	66	84	92
Total	82	91	95
Soluble BOD_5, mg/l			
Primary effluent	200	60	97
Secondary effluent	60	12	9
Soluble BOD_5 removal, percent	70	80	91

[a] mgd x 3,785 = m^3/day.

[b] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

In the following subsection on nitrification, the possible impact of the operational modifications is discussed; no definite conclusion can be drawn. For example, plant records show that the biofilter dissolved oxygen level was high even before the number of operating fans was increased; weekly average dissolved oxygen levels are shown in Figure 34. These analyses are made daily by the plant laboratory staff on grab samples taken at approximately 1:00 p.m. from the effluent collection channels. Figure 34 also indicates that dissolved oxygen (in addition to low hydraulic loadings) may have been limiting BOD_5 removal during the canning season, as measured values fell to less than 1.0 mg/l at times during August and September when removals were very low.

The most widely used design equation for plastic media trickling filtration is one which is usually termed the Velz equation, after the developer of the original version.

Several variations have been proposed over the years, and the most general form of the equation is as follows:

$$\frac{S_e}{S_o} = e^{-kA_vD^m/q^n} \tag{2}$$

where:

S_o = influent BOD_5, mg/l

S_e = effluent BOD_5, mg/l

k = treatability coefficient, dependent upon the wastewater

A_v = media specific surface area, ft^2/ft^3

D = media depth, ft

q = hydraulic loading (excluding recycle), gpm/ft^2

m,n = exponents

The values most commonly used for m and n are 1.0 and 0.5, respectively, yielding the simplified form of the Velz equation cited earlier in Section 2:

$$\frac{S_e}{S_o} = e^{-kA_vD/q^{0.5}} \tag{1}$$

Although Equation 1 is, strictly speaking, limited in its application to soluble BOD_5, it has been used, particularly by media manufacturers, with S_o and S_e representing secondary influent and secondary effluent total BOD_5, respectively.

To take into account the effect of secondary clarification on performance, it is possible to use Equation 1 with S_o representing secondary influent total BOD_5 and S_e representing secondary effluent soluble BOD_5. This approach is based upon the assumption that all of the suspended BOD_5 leaving the secondary clarifier represents solids sloughed from the media surface rather than waste material which has passed through the biofilter unoxidized. This is probably a reasonable assumption, particularly when organic loadings on the biofilter are low, as is the case for Stockton during the noncanning season. Although the assumption of influent soluble BOD_5 is inherent in the development of Equation 1, it is not inappropriate to use influent total BOD_5 in its application, particularly in view of all the other assumptions required for its development.

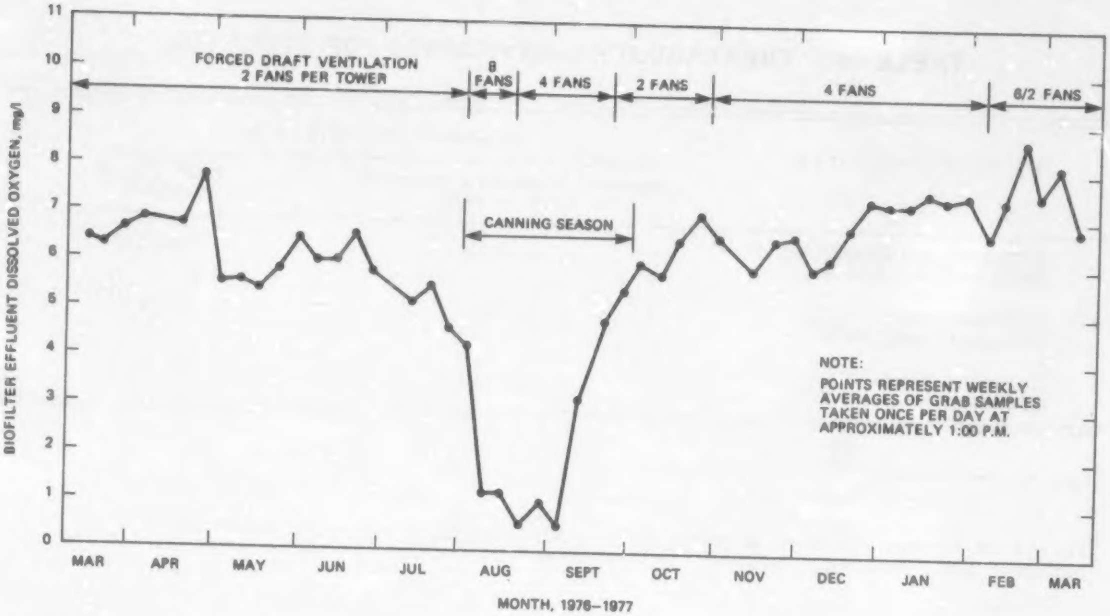


Figure 34. Biofilter effluent dissolved oxygen levels.

The treatability coefficient, k, is included in the equation to account for differences in wastewater characteristics. Shown in Table 19 are treatability coefficients for Equation 1 for the period of October 25, 1976, through March 16, 1977. This period has been chosen as representing optimal performance of the plant following the increases in hydraulic loading and air flow. The value of k in Table 19 has been adjusted to 20 C using the relation $k_T = k_{20} (1.035)^{T-20}$.

Also shown in Table 19 are treatability coefficients computed from data obtained in the 1972 pilot study (5). Comparison of the two sets shows good agreement, although values from the present study are slightly higher, meaning slightly better performance for the full-scale facility.

A common representation of the treatability coefficient is the combined parameter of $k_1 = kA_v$. For a specific surface of 89 m^2/m^3 (27 ft^2/ft^3), a value of $k_1 = 0.040$ is obtained for Stockton, using influent and effluent total BOD_5. It was noted previously in the pilot study report (5,6) that the values obtained at Stockton are somewhat lower than those normally cited for treatment of domestic waste. For example, a comprehensive review of trickling filter performance by Benjes (9) shows an average of $k_1 = 0.06$ (total BOD_5 basis) for 15 redwood and plastic media biofilter plants; values ranged from 0.03 to 0.11.

TABLE 19. TREATABILITY COEFFICIENTS FOR STOCKTON

Method of computation	Treatability coefficient[a]	
	Special sampling program, 1976 - 1977	Pilot study, 1972[b]
Influent soluble BOD_5 Effluent soluble BOD_5	0.0014	0.0013
Influent total BOD_5 Effluent total BOD_5	0.0015	0.0013
Influent total BOD_5 Effluent soluble BOD_5	0.0018	0.0015

[a] $k_{20} = \dfrac{\ln\left(\frac{Se}{So}\right)}{(1.035)^{T-20} \, A_n \, D/q^{0.5}}$

[b] Period of October through December 1972. Nitrification not suppressed in effluent BOD_5 samples. Effluent settled one hour in Imhoff Cone.

The probable cause for the slightly lower coefficients experienced at Stockton is the combination of operating the secondary system to obtain low effluent residuals under conditions of lower-than-normal organic loadings. Equations 1 and 2 are essentially empirical in nature, and extrapolation to loadings and removals outside the normal ranges is risky. In particular, very low effluent BOD_5 values are difficult to attain, as the remaining BOD_5 becomes increasingly difficult to remove. Care must be taken in applying "average" treatability coefficients, or coefficients obtained with a particular wastewater at higher loadings, when high BOD_5 removals are required. Equations 1 and 2 and their applicability to BOD_5 removal will be discussed further in Section 8.

Nitrification

Conversion of ammonia nitrogen to the nitrate form is an important function of the Stockton biofilters during the noncanning season. Presented in the following subsections are discussions on ammonia nitrogen removal, organic nitrogen removal, possible denitrification in the biofilters, and the effect of nitrification on wastewater alkalinity.

Ammonia Nitrogen Removal--

As discussed previously, poor ammonia nitrogen removal during the first portion of the study was cause for concern and led to a search for possible reasons and for measures to improve performance. Increasing the forced draft ventilation air flow and the hydraulic loading on the plastic media biofilters appear to have resulted in greater ammonia nitrogen removals during the latter portion of the study.

A summary of nitrification performance is shown in Table 20. For the period of March through July 1976, ammonia nitrogen removal averaged only 61 percent with an effluent ammonia nitrogen concentration of 5.8 mg/l. During the 4 1/2-mo period from November 1976 through March 16, 1977, removal averaged 87 percent, and the effluent ammonia nitrogen concentration averaged 2.7 mg/l. During the last 2 1/2 mo of the sampling program, removal was over 90 percent and effluent concentrations were below 2.0 mg/l. An upset from unknown causes occurred in mid-November and produced increases in both effluent BOD_5 and ammonia nitrogen levels. Without this upset, average performance results for the full 4 1/2-mo period would have been even better. Weekly primary and secondary effluent concentrations for the noncanning season are summarized in Figure 35. The improvement during the latter portion of the program is readily apparent.

TABLE 20. NITRIFICATION PERFORMANCE STUDY

Parameter	March through July 1976	November 1976 through March 1977
Flow, mgd[a]	17	17
Biofilter loading, $BOD_5/1,000\ ft^3/$ day[b]	19	21
Biofilter recirculation ratio, total applied flow/plant flow	2.7	3.8
Ammonia nitrogen		
Primary effluent, mg/l	15	21
Secondary effluent, mg/l	5.8	2.7
Removal, percent	61	87
Organic nitrogen		
Primary effluent, mg/l	10	17
Secondary effluent, mg/l	5.3	8.6
Removal, percent	47	49
Nitrate nitrogen, secondary effluent, mg/l	2.1	1.9

[a] mgd x 3,785 = m^3/day.

[b] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

The reason for the improvement is still uncertain. No attempt was made to segregate the period of increased air flow from the period of increased hydraulic loading, and neither the total hydraulic loading nor the dissolved oxygen (DO) levels were increased significantly by these actions.

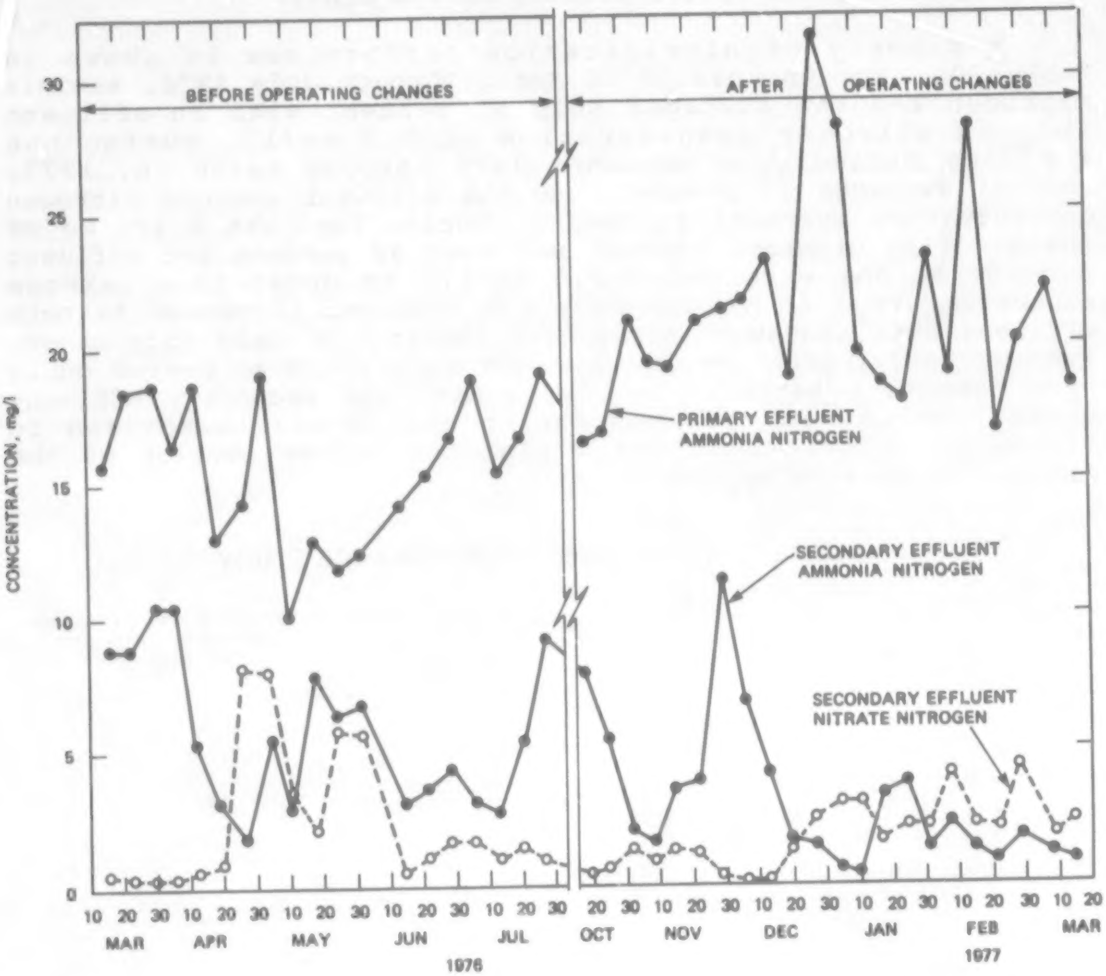


Figure 35. Ammonia and nitrate nitrogen levels.

Plotted against time in Figure 34 are the weekly average DO concentrations for biofilter effluent. For noncanning season conditions, DO levels were high, averaging 6.0 mg/l during the March-July 1976 period and 7.1 mg/l during the November 1976-March 1977 period when higher air flows were used. By contrast, the average DO level for August, the peak canning season month, was only 1.7 mg/l; the plant staff operated two to four fans per biofilter during the canning season. These figures, in themselves, do not indicate

where:

t' = total contact time (min), which reduces to:

$$t' = \frac{K}{q} \frac{q+r}{(q+r)^n} = \frac{K}{q}(q+r)^{1-n} \qquad (5)$$

K has been cited as varying between 0.5 and 1. If n = 0.5:

$$t' = \frac{K(q+r)}{q}^{1-0.5} = \frac{K(q+r)}{q}^{0.5} \qquad (6)$$

and increasing the recirculation flow, r, will increase the contact time in the biofilter. (If n = 1, increasing recirculation flow will not cause an increase in contact time.)

Thus, increasing the hydraulic loading (q+r) by 25 percent (as at Stockton) would increase the total contact time, t', by about 12 percent. This is, as with the other parameters, a fairly small increase and does not seem significant. Further, if contact time were limiting, nitrite nitrogen bleedthrough might be expected in the effluent. Although measurable concentrations of nitrite nitrogen (0.2 to 0.4 mg/l) were detected during the March-July 1976 portion of the sampling program, these values are not sufficiently high to suggest that contact time was limiting. Nonetheless, the calculations shown above do indicate that contact time may be an important parameter in nitrification performance.

Williamson and McCarty have developed a rational theory of biofilter performance which can be applied to attached growth reactors such as trickling filters (10). One of the conclusions drawn from the theory is that oxygen transfer, rather than substrate utilization, will limit nitrification when the dissolved oxygen level is less than 2.7 times the ammonia nitrogen concentration. The two operational changes which can be undertaken to increase the DO/ammonia nitrogen ratio are to increase the DO level (by increased air flow or use of high purity oxygen) or to increase recirculation, thereby diluting the ammonia nitrogen in the influent. These steps are in fact the ones which were taken at Stockton and which were followed by a significant improvement in nitrification performance.

In summary, no definite conclusion can be drawn regarding the cause of poor nitrification during the first part of the Stockton sampling program or regarding the reason for increased nitrification during the latter portion. It is highly likely that one or both of the operational changes which were that inadequate oxygen supply was the cause of the poor nitrification performance during the first part of the program. A DO concentration of 6.0 mg/l is sufficiently high to preclude inhibition of nitrification.

With the high recirculation rate employed, the DO level near the top of the tower was kept high by dilution of the incoming waste with high-DO recycled effluent. It is possible, however, that in the middle portion of the biofilter, the DO level is significantly below the concentration at the upper and lower levels. This could result in reduced nitrification.

The total hydraulic loading (including recycle) during the first part of the study was approximately 0.024 $m^3/min/m^2$ (0.6 gpm/ft^2); in October 1976 it was increased to approximately the minimum value recommended by the manufacturer for complete wetting of the media surface 0.031 $m^3/min/m^2$ (0.75 gpm/ft^2). This increase is only 25 percent and would not seem significant except for the improvement in performance obtained.

An alternative explanation for the effect of increased hydraulic loading on performance is related to the contact time of the wastewater passing through the biofilters. In contrast to carbonaceous BOD_5 removal, where the waste material can be sorbed onto the biomass and oxidized later, the conversion of ammonia nitrogen to nitrate nitrogen must occur during the time that the wastewater is in the biofilter. Thus, reduced contact times may result in poorer performance.

Contact time is related to flow by the following relationship:

$$t = \frac{K}{q^n} \tag{3}$$

where:

t = once-through contact time, min

K = coefficient

q = hydraulic loading, gpm/ft^2

n = exponent

With recirculation flow, $r(gpm/ft^2)$:

$$t = \frac{t'q}{(q+r)} = \frac{K}{(q+r)^n} \tag{4}$$

where:

t' = total contact time (min), which reduces to:

$$t' = \frac{K}{q} \frac{q+r}{(q+r)^n} = \frac{K}{q}(q+r)^{1-n} \tag{5}$$

K has been cited as varying between 0.5 and 1. If n = 0.5:

$$t' = \frac{K(q+r)^{1-0.5}}{q} = \frac{K(q+r)^{0.5}}{q} \tag{6}$$

and increasing the recirculation flow, r, will increase the contact time in the biofilter. (If n = 1, increasing recirculation flow will not cause an increase in contact time.)

Thus, increasing the hydraulic loading (q+r) by 25 percent (as at Stockton) would increase the total contact time, t', by about 12 percent. This is, as with the other parameters, a fairly small increase and does not seem significant. Further, if contact time were limiting, nitrite nitrogen bleedthrough might be expected in the effluent. Although measurable concentrations of nitrite nitrogen (0.2 to 0.4 mg/l) were detected during the March-July 1976 portion of the sampling program, these values are not sufficiently high to suggest that contact time was limiting. Nonetheless, the calculations shown above do indicate that contact time may be an important parameter in nitrification performance.

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In summary, no definite conclusion can be drawn regarding the cause of poor nitrification during the first part of the Stockton sampling program or regarding the reason for increased nitrification during the latter portion. It is highly likely that one or both of the operational changes which were instituted were effective in aiding performance. In designing trickling filter nitrification systems, provision of adequate air supply and recirculation appear to be very important.

Organic Nitrogen Removal--

Poor organic nitrogen removals, approximately 25 percent, were obtained during the 1972 pilot study (5,6). It was noted that the reactions involving conversion of organic nitrogen to ammonia nitrogen (which can then be converted to the nitrate form) are slow and usually quite incomplete in biological treatment processes. Clarification is often the principal removal mechanism since much of the organic nitrogen is in the insoluble form.

Organic nitrogen removals obtained during the present sampling program were also low, averaging about 48 percent for the noncanning season and 24 percent for August and September 1976, the peak months of the canning season.

Nitrogen Mass Balance--

Nitrification in biological treatment processes is normally manifested by high secondary effluent nitrate nitrogen concentrations (10 to 25 mg/l). The data gathered for this study showed an overall average of 2.0 mg/l (noncanning season) with a maximum monthly value of 5.0 mg/l in May 1976. Even when effluent ammonia nitrogen concentrations were less than 2.0 mg/l in January-March 1977, nitrate nitrogen concentrations ranged only from 2.2 to 2.9 mg/l.

To provide insight into this phenomenon, a nitrogen mass balance for the secondary treatment process is given in Table 21. Primary and secondary effluent concentrations are given for ammonia, organic, nitrite, and nitrate nitrogen. Also shown is the estimated quantity of nitrogen assimilated into the biomass. This value was computed by assuming that the biofilter effluent volatile suspended solids contain 5 percent nitrogen. Nitrogen concentrations normally cited for activated sludge or trickling filter humus range from about 3 to 7 percent (11,12).

For the canning season months of August and September, the biofilter influent nitrogen concentration equals the computed biofilter effluent concentration, 34 mg/l. This indicates that the assumption of 5 percent nitrogen in the biofilter effluent volatile suspended solids is reasonable. For the noncanning season portion of the sampling program, the influent nitrogen concentration exceeds the effluent concentration by 8 mg/l (28 mg/l for influent; 20 mg/l for effluent).

The cause of the apparent nitrogen loss through the biofilters is uncertain. Denitrification (conversion of nitrate to nitrogen gas) within the anaerobic portion of the biomass is a plausible reason. A second possible explanation is that the biofilter effluent suspended solids contain a higher concentration of nitrogen than assumed above. If the effluent volatile suspended solids are assumed to consist solely of biological cells sloughed from the media surface (most applicable to the noncanning season), then nitrogen concentration may be estimated. The formula $C_5H_7NO_3$ is often cited as being representative of cell material (13). The nitrogen fraction then would be 12 percent of the effluent volatile suspended solids concentration. Using this assumption, the assimilated nitrogen concentration for the noncanning season increases to 13 mg/l, which would give a biofilter effluent nitrogen concentration of 26 mg/l in Table 21, very close to the influent concentration of 28 mg/l. Although the nitrogen concentration of the biofilter effluent solids at Stockton was not measured, all the values reported in the literature are significantly lower than 12 percent.

TABLE 21. NITROGEN MASS BALANCE

Parameter	Concentration, mg/l	
	Noncanning season[a]	Canning season[b]
Primary effluent		
Ammonia nitrogen	18	18
Organic nitrogen	10	16
Nitrite nitrogen	<0.1	<0.1
Nitrate nitrogen	<0.1	<0.1
Total	28	34
Secondary or biofilter effluent[c]		
Ammonia nitrogen	4.3	12
Organic nitrogen	6.5	13
Nitrite nitrogen	0.2	<0.1
Nitrate nitrogen	2.0	<0.1
Assimilated nitrogen[d]	7.3	9.3
Total	20	34
Difference, primary effluent minus biofilter effluent	8	0

[a] March - July 1976; November 1976 - March 1977.

[b] August - September 1976.

[c] Secondary effluent concentrations used for ammonia, organic, nitrite, and nitrate nitrogen; biofilter effluent used for assimilated nitrogen.

[d] Assimilated nitrogen = 0.05 x biofilter effluent VSS.

Alkalinity and pH--

Conversion of ammonia nitrogen to nitrate nitrogen in biological treatment is accompanied by the destruction of alkalinity. A potential problem results from the possible subsequent depression of pH and associated inhibition of nitrification rates. The effect is mediated by the stripping of carbon dioxide from the liquid by the process of aeration, which tends to elevate the pH level. In enclosed systems such as the high purity oxygen activated sludge process, the carbon dioxide is less efficiently stripped from the liquid and pH depression can be severe.

Monthly primary and secondary effluent alkalinity concentrations from Stockton are shown in Figure 36. Greater drops in alkalinity, and lower total concentrations, occurred in the noncanning season. A greater alkalinity drop occurred during the last portion of the study and is associated with the higher BOD_5 and ammonia nitrogen removals achieved at that time.

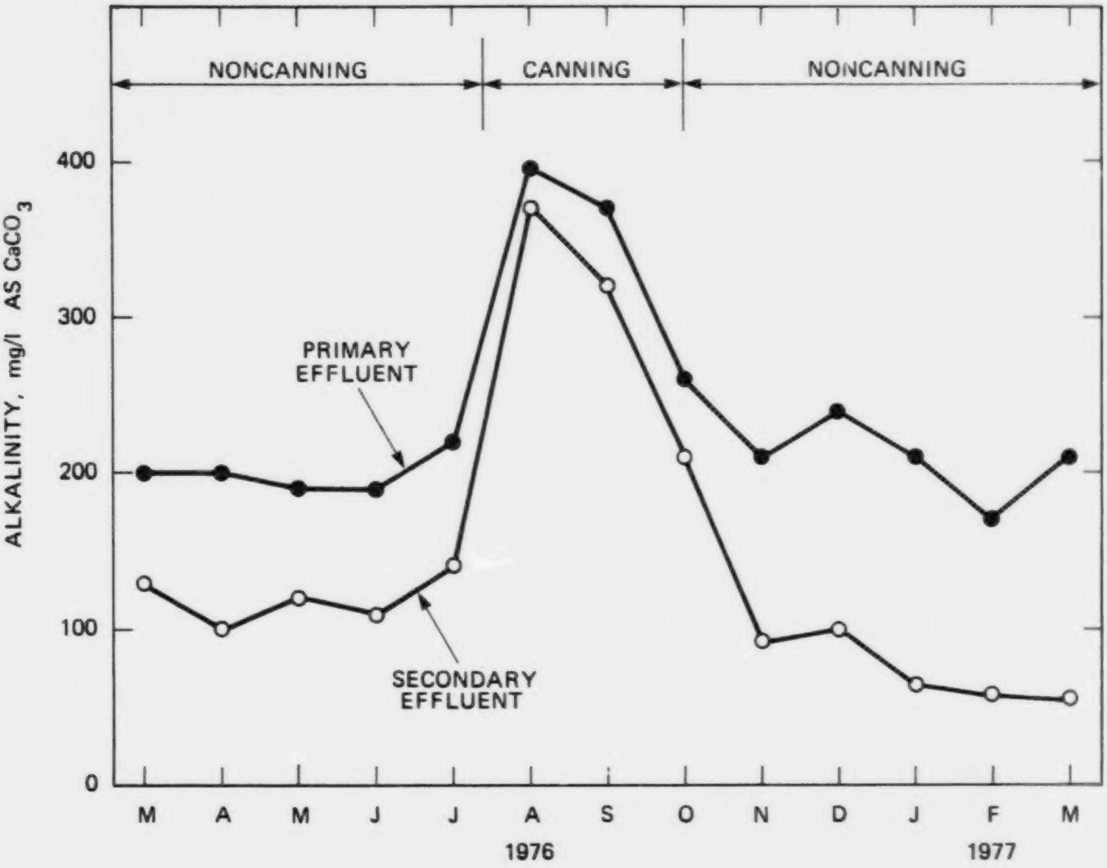


Figure 36. Alkalinity destruction.

It can be calculated that 7.1 mg of alkalinity as $CaCO_3$ is destroyed per mg of ammonia nitrogen oxidized. Measured values range from about 6.0 to 7.4 mg/mg (14). Attempts to calculate alkalinity destruction ratios for the Stockton data result in a value of 10 mg alkalinity as $CaCO_3$ destroyed per mg ammonia nitrogen oxidized. The higher value probably results from other reactions occurring in the secondary treatment process and indicates that in combined carbon/nitrogen oxidation systems, alkalinity destruction cannot be predicted on the basis of ammonia nitrogen oxidation alone.

Carbon dioxide stripping due to the high air flow through the Stockton biofilters apparently offset the effect of alkalinity destruction during the noncanning season months as the pH level rose in passing through the secondary system from 6.9 to 7.4. During the canning season months of August and September, pH levels dropped from 8.7 to 8.3 in the secondary treatment process.

Suspended Solids

Questions regarding the ability of plastic media trickling filters to produce an effluent with a low suspended solids concentration have been voiced increasingly during the past few years. The principal reason is the federal guidelines which specify a monthly average effluent suspended solids concentration of 30 mg/l or less to provide secondary treatment as mandated by the 1972 Federal Water Pollution Control Act Amendments.

Data collected during the 1-yr sampling program at Stockton (Table 14) showed that the 30 mg/l requirement was not met during three of the ten noncanning season months. There appear to be three principal reasons for this: (1) high clarifier overflow rates, (2) poor clarifier hydraulic characteristics, and (3) possible short circuiting caused by temperature/density gradients set up in the secondary clarifiers. The last item, possible temperature density gradients, as described below, is still a nebulous concept at this time but is an intriguing possibility which should be explored further.

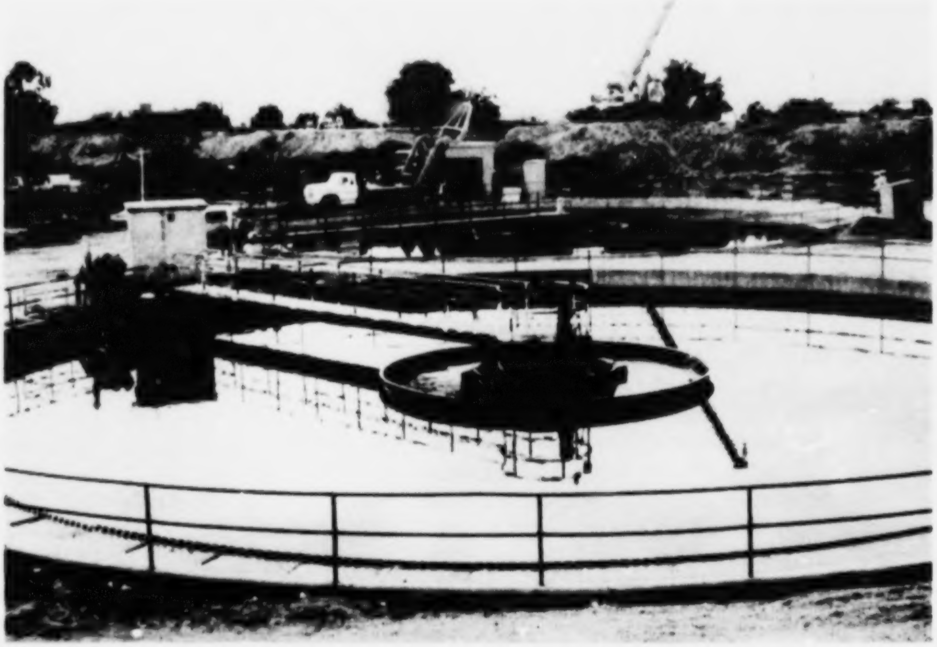


Figure 37. Secondary clarifier. Poor hydraulic distribution and short circuiting may have hindered overall secondary treatment performance.

The four existing secondary clarifiers (Figure 37) at Stockton have been in use for many years, and their number has not been increased even though the overall capacity of the plant has been increased several times. At a design noncanning season flow of 87,000 m^3/day (23 mgd), use of all four clarifiers would result in an overflow rate of approximately 30 m^3/day/m^2 (730 gpd/ft^2). As noted above, practice has been to use only three of the four clarifiers during the noncanning season, resulting in experienced overflow rates of about 40 m^3/day/m^2 (970 gpd/ft^2). Such values are close to traditional design loadings for secondary clarifiers following biofiltration. Historically, however, such systems have not been designed to meet the lower effluent suspended solids and BOD_5 concentrations now required. Even though performance requirements have become more stringent, there has been a tendency to continue sizing secondary clarifiers as in the past, which may, in some cases, be responsible for difficulties in attaining low suspended solids levels.

The second possible cause of the high measured secondary effluent suspended solids levels is poor hydraulic characteristics in the clarifiers. Poor flow distribution among the clarifiers has been a chronic problem, and within each clarifier, uneven effluent weirs have resulted in a large fraction of the flow passing over a small percentage of the weir length. Although the plant staff has undertaken minor maintenance to improve the flow characteristics, major repairs had not been made up to the time of the present study because the buffering effect of the tertiary oxidation ponds made less than optimum performance of the secondary clarifiers tolerable. Modifications to the effluent troughs were implemented subsequent to completion of this study, and these should result in improved performance in the future.

The third possible reason for high effluent suspended solids concentrations is related to the wastewater temperature drop caused by the forced draft ventilation system. The low hydraulic loadings (excluding recycle) and high air flows which must be used for nitrification mean that the biofilters act like cooling towers. Wastewater temperature drops of 5 C through the biofilters were measured at mid-day (on a cold day with air temperature approximately 8 C) during the study.

A phenomenon to which these high temperature drops can be hypothetically related had been occurring at the plant. Observation of the secondary clarifiers during the middle of the day showed an increase in turbidity and apparent short circuiting of influent which rose to the surface near the feedwell and moved rapidly across the clarifier to the effluent troughs. This phenomenon had been observed for some time by the plant staff, but no explanation had been found for its occurrence. On one occasion, a dye tracer was added to the clarifier at the influent while the phenomenon was occurring, and in approximately 5 min, the dye was observed passing over the effluent weir. This indicates that the short circuiting was severe.

After observing the phenomenon for several months during the sampling program, it was theorized that the short circuiting may have been due to temperature/density gradients set up within the clarifier. With low hydraulic loadings and high air flows to promote nitrification in the towers, colder air temperatures and lower flows at night resulted in a greater cooling of the wastewater as it passed through the towers. As the wastewater flow and temperature increased in the morning hours, the drop in wastewater temperature through the towers would decrease and the water entering the clarifiers would be warmer and lighter. If the difference in density was sufficiently great and if the change from cold to warm water occurred sufficiently rapidly, short circuiting of the type observed might be expected to occur.

On several occasions, a dissolved oxygen/temperature probe was used to measure temperature in the secondary clarifiers to determine whether density gradients of the type described above might exist. Measurements did show that temperature gradients occurred within the clarifiers, but correlation of these gradients with the observed short circuiting was difficult. Nonetheless, after consultation with the plant staff, it was decided to operate the fans in such a way as to counter the phenomenon. Two fans were operated at night between the hours of 8 p.m. and 8 a.m. when air temperatures and wastewater flows were low. Six fans were operated between the hours of 8 a.m. and 8 p.m. With fewer fans operating at night, the temperature drop through the towers would be decreased. Thus, the 24-hr variation in tower effluent temperature should be decreased, and problems resulting from short circuiting should be diminished.

The results of this operational modification were inconclusive. The short circuiting phenomenon continued to occur, but the occurrences appeared (from visual observation) to be less frequent and less severe than they had been previously. Twenty-four-hr average suspended solids concentrations decreased dramatically during the initial period following the change in procedure, indicating that the change had an important beneficial effect on performance. During the last 2 wk of the program, however, effluent concentrations again rose, leaving doubt concerning the proposed explanation for the observed phenomenon and the methods used to eliminate it.

Weekly average secondary effluent suspended solids concentrations for the last 5 mo of the study are shown in Figure 38. Large variations are seen to occur through the period. The very high levels in late November occurred at the same time that effluent ammonia nitrogen and BOD_5 levels increased, indicating an overall upset in the secondary treatment process. The period of February 2 through March 2 produced consistently low suspended solids concentrations, averaging 18 mg/l, with a high daily value of 25 mg/l (13 measurements). The overall February 2-March 16, 1977, average was 21 mg/l, compared to an average of 30 mg/l for the period from October 25, 1976, through February 1, 1977, when four fans were operated continuously.

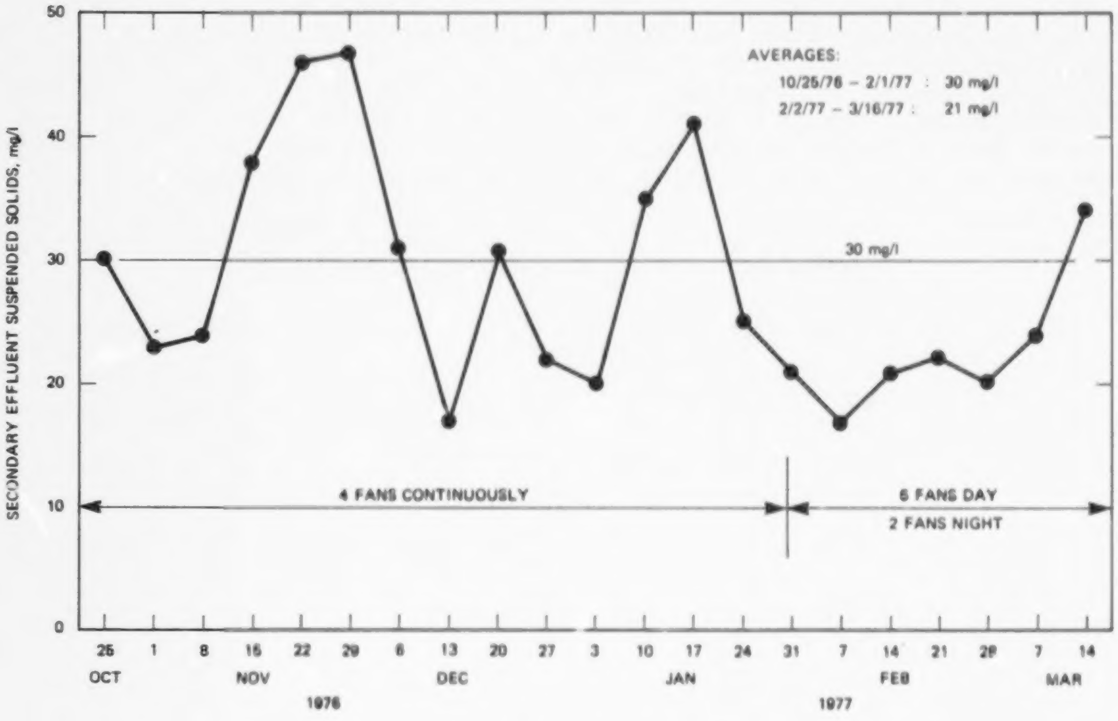


Figure 38. Secondary effluent suspended solids levels.

There is no apparent cause for the increase during the final 2 wk. Inspection of unsettled biofilter effluent data shows no increase in suspended solids levels which would be associated with periodic sloughing of the media surface.

In summary, the cause of the short circuiting is still not known. Temperature/density gradients may be the cause, although the density gradients which would occur are small. Temperature gradients were observed within the clarifiers, but they could not be correlated with the presence of short circuiting. Attempting to reduce or eliminate the density gradients by varying the number of forced draft ventilation fans seemed, from visual observation, to reduce the severity of short circuiting. Daily averages of secondary effluent suspended solids concentrations dropped markedly for a 1-mo period following the change in fan operation but increased again during the final 2 wk of the sampling program without explanation.

Secondary Treatment Solids Production

Total and waste secondary (or biological) solids production, is summarized in Table 22 on both BOD_5 and COD bases. Waste secondary solids production is computed by subtracting the solids in the secondary effluent; it represents the quantity of secondary sludge to be processed by the plant's solids handling system. Total secondary volatile solids production averaged 0.43 kg/COD removed and 0.67 kg/kg BOD_5 removed. Total secondary influent and soluble secondary effluent COD or BOD_5 values were used in the computations.

TABLE 22. SECONDARY SOLIDS PRODUCTION

Month 1976-77	BOD_5 basis				COD basis			
	Total solids production[a]		Waste solids production[b]		Total solids production[a]		Waste solids production[b]	
	kg TSS/ kg BOD_5 removed	kg VSS/ kg BOD_5 removed	kg TSS/ kg BOD_5 removed	kg VSS/ kg BOD_5 removed	kg TSS/ kg COD removed	kg VSS/ kg COD removed	kg TSS/ kg COD removed	kg VSS/ kg COD removed
March	0.93	0.60	0.69	0.41	0.47	0.30	0.34	0.21
April	1.0	0.79	0.81	0.63	0.50	0.39	0.40	0.31
May	1.3	0.92	1.1	0.76	0.70	0.48	0.59	0.40
June	1.1	0.69	0.75	0.45	0.70	0.45	0.49	0.30
July	1.2	0.92	0.98	0.78	0.75	0.60	0.64	0.51
August	1.0	0.83	0.73	0.62	0.59	0.51	0.46	0.39
September	0.71	0.57	0.50	0.39	0.44	0.35	0.31	0.24
October	0.80	0.65	0.57	0.44	0.32	0.42	0.36	0.28
November	0.67	0.57	0.50	0.42	0.50	0.43	0.37	0.31
December	0.64	0.50	0.52	0.40	0.44	0.34	0.36	0.27
January	0.67	0.48	0.52	0.36	0.50	0.36	0.39	0.27
February	0.94	0.71	0.83	0.61	0.67	0.50	0.59	0.43
March	0.83	0.67	0.69	0.57	0.50	0.40	0.41	0.34
Average	0.83	0.67	0.65	0.51	0.54	0.43	0.43	0.33

[a] Total solids production = secondary system waste sludge solids + secondary effluent solids.

[b] Waste solids production = secondary system waste sludge only.

Comparison of solids production during the noncanning season before and after the operational modifications shows a substantial decrease for the latter period. For example, total volatile solids production averaged 0.78 kg/kg BOD_5 removed for the March-July 1976 period. For the November 1976-March 1977 period with higher hydraulic loadings and air flows, production averaged 0.59 kg/kg BOD_5 removed.

The lower production during the latter portion of the study may be due to higher DO levels resulting from increased air supply. It is a well-known fact that in the activated sludge process, adequate DO levels are necessary to minimize sludge production. The same phenomenon may be applicable to trickling filtration.

DESIGN AND PERFORMANCE

Shown in Table 23 is a comparison between performance predicted for the Stockton biofilters and that obtained during the 1976-77 sampling program.

TABLE 23. DESIGN AND PERFORMANCE COMPARISON

Parameter	Canning season		Noncanning season	
	Design[a]	Actual[b]	Design	Actual[c]
Flow, mgd[d]	58	39	23	17
Trickling filter loading				
BOD_5, mg/l	390	320	170	210
BOD_5, lb/1,000 ft^3/day[e]	110	73	19	21
Suspended solids, mg/l	155	220	60	160
Secondary effluent				
BOD_5, mg/l	120	130	17	17
BOD_5 removal, percent	70	59	90	92
Suspended solids, mg/l	165	51	35	27
Ammonia nitrogen, mg/l	-	-	-	2.7

[a] Maximum month.

[b] August 1976.

[c] November 1976 - March 1977.

[d] mgd x 3,785 = m^3/day.

[e] lb/1,000 ft^3/day x 0.016 = kg/m^3/day.

The peak month of August 1976 was used to represent the canning season in comparison with the maximum month projected values. The period of November 1976 through March 1977 was used to represent the noncanning season; this followed the operational changes which were made in an attempt to improve nitrification performance. Performance during this period was better than that obtained during the first part of the sampling program, from March through July 1976, and represents what is believed to be optimal plant performance.

Flows for both the canning and noncanning seasons were below design capacity. The biofilter organic loading is well below design for the canning season but slightly above the design loading for the noncanning season due to higher than expected primary effluent BOD_5 concentrations.

Maximum month canning season BOD_5 removal averaged 59 percent, below the projected value of 70 percent even though the loading was relatively low, 1.17 kg/m^3/day (73 lb/1,000 ft^3/day). It is likely that if the operational changes discussed previously had been in effect during the canning season, greater BOD_5 removal would have resulted. Biofilter effluent DO levels, in particular, were very low during the canning season and would have benefitted from a greater number of fans being operated.

Noncanning season BOD_5 removal for the November 1976-March 1977 period essentially met the projected performance levels, with an average effluent concentration of 17 mg/l and an average removal of 92 percent.

The canning season effluent suspended solid concentration was 51 mg/l, far better than the predicted value of 165 mg/l, which seems high, even when the higher clarifier loading rates which would occur at design flow are considered. The non-canning season average of 27 mg/l is below the projected level of 35 mg/l. Possible methods of ensuring the "secondary treatment" level of 30 mg/l suspended solids are discussed in Section 8.

Although no secondary effluent ammonia nitrogen level was specified in the design data, the average over the last portion of the sampling program was 2.7 mg/l. At a comparable loading during the 1972 pilot study, an effluent concentration of 2.0 mg/l was obtained.

In summary, after making operational changes, specifically increasing the forced draft ventilation air flow and increasing recirculation, performance improved to the level anticipated. It is not certain if these changes actually caused the improvement in performance, but the correlation between the changes and improved performance is definite.

Besides the question of which operational change, increased air flow or increased recirculation, improved performance (or whether both or neither helped), the major remaining question regarding performance involves the cause of the short circuiting (with consequent high effluent suspended solids levels) which occurred in the secondary clarifiers. It has been hypothesized that temperature/density gradients set up in the clarifiers caused the short circuiting. Attempts to measure temperature gradients were inconclusive, and it remains for future investigations to determine the cause of the observed phenomenon.

TREATMENT COSTS

Total construction cost for an engineering project such as conversion of the Stockton trickling filters includes not only the contract cost, but expenses for design and construction inspection. Presented in Table 24 are total construction costs for modification of the Stockton secondary treatment facilities. The total cost of $3,953,000 is associated with an ENR Construction Cost Index of 2200 for the San Francisco area in July 1973, the approximate midpoint of the construction period.

TABLE 24. CONSTRUCTION COST FOR TRICKLING FILTER CONVERSION

Component	Cost, thousand dollars
Secondary treatment modifications	1,820
Filter media supply and installation	1,840
Engineering design	234
Resident engineering[a]	59
Total construction cost	3,953

[a] Does not include construction inspection services provided by city staff.

A breakdown of the successful secondary treatment modification bid is presented in Table 25. This breakdown was prepared by the contractor prior to beginning of construction and was used as the basis for construction progress payments. The total cost shown in Table 25, $1,722,000, is lower than the total shown for secondary treatment modifications in Table 24, $1,820,000, because of change orders during construction.

Annual operation and maintenance (O&M) cost for the Stockton Regional plant are presented in Table 26 for fiscal years 1975 and 1976. Principal cost increases between these 2 yr are in the categories of utilities (principally gas and electricity), chemicals (chlorine for disinfection and ammonia gas for use as a nutrient supplement in the ponds and biofilters during the canning season), and motor pool expenses (which may be principally due to gasoline costs). The overall increase from fiscal year 75 to fiscal year 76 was 41 percent. Chemical costs accounted for the biggest increase, 106 percent.

Presented in Table 27 is an estimate of the percentage of operation and maintenance labor hours associated with each major unit process in the plant. The highest, by far, 52 percent, is for preliminary and primary treatment which includes grit removal, bar screening, flow measurement, raw sewage pumping, and primary sedimentation. Secondary treatment, including the rock and plastic media trickling filters, filter recirculation, and secondary clarification, accounts for 17 percent of the total.

TABLE 25. SECONDARY TREATMENT MODIFICATIONS BID BREAKDOWN

Item	Description	Quantity	Unit	Unit price, dollars/unit	Cost, dollars
1	Demolition	Lump sum		-	50,000
2	Removal and disposal of existing media	9,700	yd^3[b]	10	97,000
3	Structural excavation	1,840	yd^3[b]	25	46,000
4	Structural backfill	910	yd^3[b]	15	13,650
5	In-place concrete	1,570	yd^3[b]	225	353,250
6	In-place precast concrete	24,000	lineal ft[c]	7.50	180,000
7	In-place masonry	29,550	ft^2[d]	4.00	118,200
8	Miscellaneous metal	34,000	lb[e]	1.50	51,000
9	60 in.[a] distribution pipe	360	lineal ft[c]	110	39,600
10	48 in.[a] filter return pipe	80	lineal ft[c]	150	12,000
11	48 in. foul air duct	172	lineal ft[c]	125	21,500
12	36 in. effluent supply and pipe collection	924	lineal ft[c]	70	64,600
13	Filter distributors	3	Each	41,600	124,800
14	Filter supply pumps	3	Each	22,000	66,000
15	Filter circulation pumps	2	Each	12,500	25,000
16	42 in.[a] by 42 in.[a] sluice gates	5	Each	5,000	25,000
17	Furnish and install fans	24	Each	800	19,200
18	Painting	Lump sum	-	-	60,000
19	12/20.8 SV switch station	Lump sum	-	-	34,900
20	Modify existing MCC	Lump sum	-	-	18,300
21	New MCC	Lump sum	-	-	26,000
22	1000 KVA substation	Lump sum	-	-	22,000
23	750 KVA substation	Lump sum	-	-	18,250
24	Buried 4 in.[a] conduit in duct	2,600	lineal ft[c]	14	36,400
25	Buried 3 in.[a] conduit in duct	8,100	lineal ft[c]	3	24,300
26	Buried 1 in.[a] conduit in duct	10,400	lineal ft[c]	2.50	26,000
27	Buried 23 KV conduit in duct	8,300	lineal ft[c]	5.00	41,500
28	Paving	2,000	Ton[f]	14.50	29,000
29	Other work	Lump sum	-	-	28,470
	Subtotal				1,672,000
	Contingency				50,000
	Total				1,722,000

[a] in. x 2.54 = cm.

[b] yd^3 x 0.765 = m^3.

[c] lineal ft x 0.305 = lineal m.

[d] ft^2 x 0.929 = m^2.

[e] lb x 0.454 = kg.

[f] ton x 0.907 = metric ton.

TABLE 26. OPERATION AND MAINTENANCE COSTS

Category	Annual operation and maintenance cost, thousand dollars/year[a] 1974-75[b]	1975-76[c]
Salaries, fringe benefits, and overhead	556	651
Utilities	103	152
Chemicals	156	322
Materials and supplies	47	92
Professional services	33	45
Motor pool	36	57
Other	4	4
Total	935	1,323

[a] Estimated from records which include cost of a second, smaller plant operated by the City.

[b] FY 1975.

[c] FY 1976.

TABLE 27. OPERATION AND MAINTENANCE LABOR ASSOCIATED WITH MAJOR PLANT COMPONENTS

Process	Estimated amount of operation and maintenance labor associated with process, percent
Preliminary and primary treatment	52
Secondary treatment (trickling filters)	17
Oxidation ponds	12
Chlorination	4
Solids handling	15

SECTION 8

GENERAL DESIGN CONSIDERATIONS

Upgrading a conventional rock media trickling filter plant through conversion to plastic media may be an economical, efficient way for many communities to obtain improved wastewater treatment through maximum use of existing facilities. In determining whether plastic media trickling filtration should be selected for use at a particular plant, questions must be asked concerning the ability of the process to meet effluent quality requirements, the physical condition of existing structures, the ability of existing pipes and pumping facilities (with necessary modifications) to receive increased flows, and the ability to maintain adequate treatment capability during construction. Working with an existing plant configuration may impose particular design constraints; for example, inability to bypass during construction may affect design, or the plant configuration may make future expansion difficult. Comparison of plastic media trickling filtration with alternative treatment processes such as the activated sludge process must be made with full knowledge of all these factors. If plastic media trickling filtration is selected for use, anticipation of design and construction problems will be very important as the detailed design and construction phases follow.

It is the purpose of this section to present information on design considerations for conversion of rock media trickling filters to plastic media. Material presented here is based on the information from Sections 4 through 7, data from conversions at other wastewater treatment plants, manufacturers' information, and the technical literature. As in Section 5, the subject of design has been divided into two categories, process design and physical design. The information presented under each category is intended to be useful in both the planning and detailed design engineering phases of treatment plant upgrading.

PROCESS DESIGN

Difficulty in describing the trickling filtration process mathematically has resulted in most designs being based on empiricism, experience, standard practices, and, occasionally, pilot investigations. Increased use of plastic media has resulted in an increased use of equations which, although developed on a semirational basis, remain essentially empirical in nature. Coefficients determined from experience or from pilot studies are inserted into the equation, and the required media volume and loading parameters can be determined. Generally, however, such design parameters as media depth, hydraulic loading, and specific surface area are constrained within certain ranges by various factors, and the design parameter which can be varied over the greatest range is organic loading in kg BOD_5/m^3/day (lb/1,000 ft^3/day) or, in the case of separate-stage nitrification, ammonia nitrogen loading in kg NH_4^+-N/m^2 media surface area/day (lb/1,000 ft^2/day).

Items covered below under process design include media selection, BOD_5 removal, nitrification, oxygen transfer, ventilation, secondary clarification, and solids production.

Media Selection

Plastic trickling filter media falls into two main types: corrugated sheet modules (e.g., B. F. Goodrich's Vinyl Core) and dumped media. Shown in Table 28 are representative examples of each type along with the specific surface area for each (other values may be available). Lower specific surface areas are used for BOD_5 removal or combined carbon oxidation-nitrification. Higher values are used for separate-stage nitrification.

Shown on Figure 39 is a module of B. F. Goodrich's Vinyl Core II synthetic media with specific surface areas which can range from 72 to 121 m^2/m^3 (22 to 37 ft^2/ft^3). In Figure 40 is a high-specific-surface-area media, Koro-Z, manufactured by B. F. Goodrich for separate-stage nitrification. Available specific surface areas range from 138 to 217 m^2/m^3 (42 to 66 ft^2/ft^3).

BOD_5 Removal

Removal of oxygen demanding substances from the waste stream has historically been the most important performance parameter for trickling filters. Rock trickling filter BOD_5 removal efficiencies generally range from 60 to 85 percent with effluent concentrations between 35 and 75 mg/l. Many investigators have proposed equations to predict trickling filter BOD_5 removal, including the National Research Council (NCR),[4] Galler and Gotaas,[15] Fairall,[16] and Rankin.[17] The concept on which most present-day plastic media design relationships are based was first proposed by Velz[18] in 1948:

$$\frac{S_e}{S_o} = 10^{-k_2 D} \qquad (7)$$

where:

S_e = effluent BOD_5

S_o = influent BOD_5

D = media depth

k_2 = rate coefficient

It is based on the principal that the rate of extraction of organic matter is proportional to the amount remaining, or:

$$\frac{dS}{dt} = -k_2 t \tag{8}$$

In integrated form, the equation is:

$$\frac{S_e}{S_o} = e^{-k_3 t} \tag{9}$$

where:

S_e = effluent BOD_5

S_o = influent BOD_5

k_3 = rate coefficient

Equation 9 is equivalent to Equation 7 if the contact time, t, is assumed to be proportional to depth and if base 10 logarithms are converted to natural logarithms.

Variations of Equation 9 usually include some or all of the following additional parameters:

$$\frac{S_e}{S_o} = e^{-kA_v D^m / q^n} \tag{2}$$

where:

A_v = media specific surface area, ft^2/ft^3

q = hydraulic loading (excluding recycle), gpm/ft^2

k,m,n = coefficients

TABLE 28. EXAMPLES OF AVAILABLE PLASTIC MEDIA

Manufacturer	Trade name	Type	Specific surface area available,[c] ft^2/ft^3[d]
Envirotech Corp., California[a]	Surfpac	Corrugated sheet modules	27
B.F. Goodrich, Marietta, Ohio	Vinyl Core	Corrugated sheet modules	30.5 45
Enviro Development Co., Inc. Palo Alto, California[b]	Flocor	Corrugated sheet modules	27 40
Mass Transfer, Ltd., Houston, Texas	Filterpack	Dumped rings	36 57
Norton Co., Akron, Ohio	Actifil	Dumped rings	27 42
Munters Corp., Ft. Meyers, Florida	PLASdek	Corrugated sheet modules	42 68

[a] Formerly available from the Dow Chemical Co., Midland, Michigan.

[b] Under license from ICI, Great Britain; formerly available from the Ethyl Corp., Baton Rouge, Louisiana.

[c] Representative values only; other specific surfaces may be available.

[d] $ft^2/ft^3 \times 3.28 = m^2/m^3$.

The inclusion of A_v in the relation is intended to reflect the better treatment provided by more slime surface area per unit volume as provided by a higher specific surface area. The term q is included to show that the contact time may be decreased by an increase in the hydraulic loading on the filter and, thus, is affected by q as well as D.

The exponents m and n have generally been cited as ranging from 0.5 to 1.0, with 1.0 the most commonly mentioned value for m and 0.5 or 0.67 the most common value for n. The coefficients k, k_2, or k_3 (or k_1 where $k_1 = kA_v$) are termed treatability coefficients and are considered to be determined by characteristics of the wastewater. Treatability coefficients for domestic wastewaters are fairly predictable, but those for industrial wastes are more variable. Often, pilot tests are run to determine the treatability of specific industrial wastes.

The most commonly used form of Equation 2 appears to be:

$$\frac{S_e}{S_o} = e^{-k_1 D/q^{0.5}} \qquad (10)$$

This form of the equation is used by several plastic media manufacturers for design purposes.

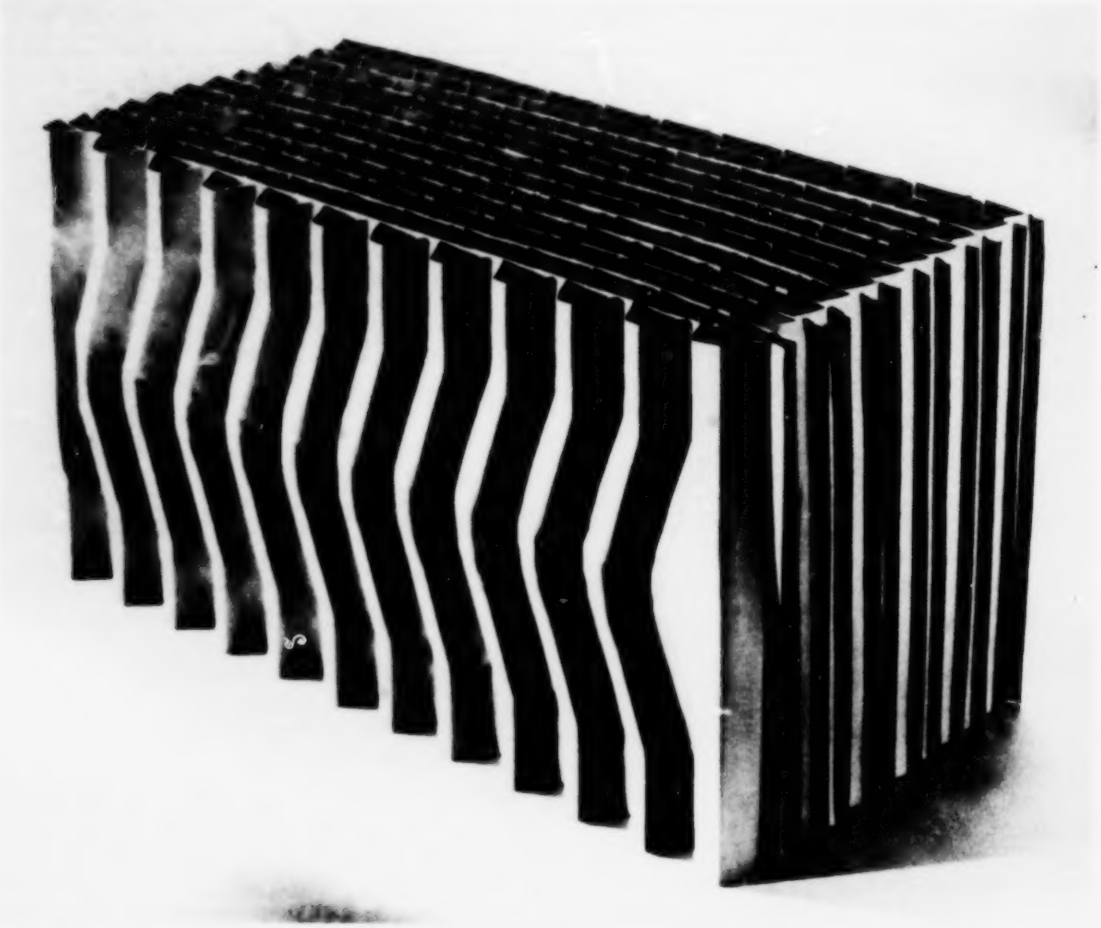


Figure 39. B. F. Goodrich's Vinyl Core II plastic media module (photograph courtesy B. F. Goodrich).

While these equations can be useful in predicting performance, they are limited in important respects. The treatability coefficient is often determined by more than merely the character of the waste, and certain factors limit the usable ranges of specific surface area, depth, and hydraulic loading. The various parameters of Equation 2 are discussed briefly below.

Influent and Effluent BOD_5 Values--

Equation 2 is employed almost universally for situations where primary effluent is treated by the trickling filter. Usually, total (soluble plus suspended) BOD_5 values are used for influent and secondary clarifier effluent concentrations, since they are the values most often measured and because discharge requirements are written in terms of total BOD_5.

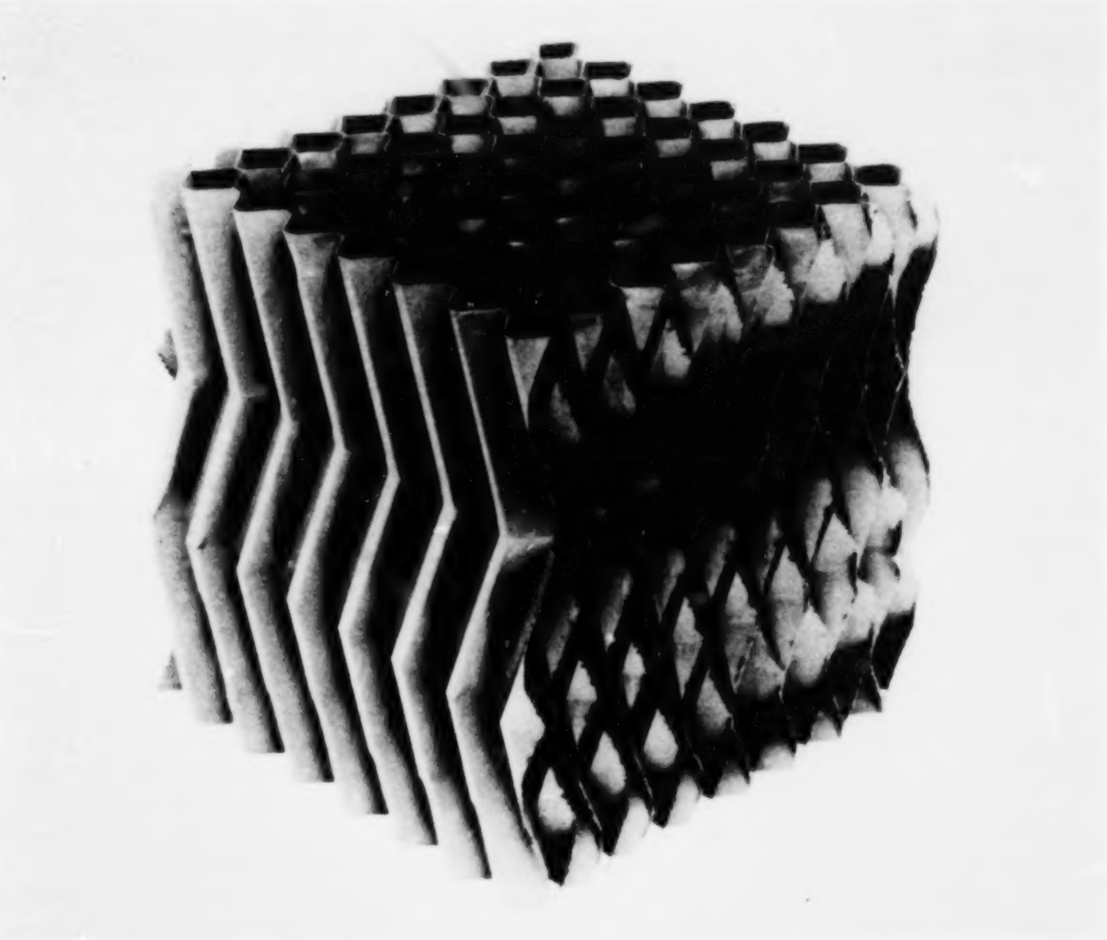


Figure 40. B. F. Goodrich's Koro-Z plastic media module. This is a high-specific surface-area plastic media option which can be used for separate-stage nitrification applications (photograph courtesy B. F. Goodrich).

Much of the published theory on biological treatment kinetics uses influent and effluent soluble BOD_5 concentrations. While this may allow more rational development of kinetic models, application to specific design situations becomes difficult.

Utilization of influent total BOD_5 and effluent soluble BOD_5 offers specific advantages in applying the basic design equation. Although Equation 2 may not be strictly applicable to the removal of suspended biodegradable material, values of total influent BOD_5 are nearly always available for planning or design purposes.

It is, therefore, convenient to use influent total BOD_5 values in design. Inaccuracies will be minimal where domestic wastewater is being treated and the fraction of soluble BOD_5 is fairly consistent. In dealing with industrial wastes, pilot studies may need to be undertaken with loading parameters near those anticipated for design. This will reduce the necessity of extrapolating results, which can result in inaccuracies.

Suspended BOD_5 in the trickling filter (and secondary clarifier) effluent consists principally of particles sloughed from the media surface and do not represent material which has passed through the filter unoxidized. This is particularly true when loadings are low and treatment efficiency is high. (It is less true when the trickling filter is used in a roughing mode under high loadings.)

The ability of a secondary treatment system to produce effluents with low suspended BOD_5 concentrations is primarily dependent upon solids separation efficiency. It is therefore reasonable to use effluent soluble BOD_5 when discussing performance of the trickling filter alone, i.e., in applying Equations 2 or 10.

The Stockton data provides evidence that it is possible to produce secondary effluents containing soluble BOD_5 concentrations of less than 10 mg/l with plastic media trickling filters. Tertiary, multi-media filtration can then be expected to produce an effluent with a total BOD_5 concentration near this value. Other methods of improving solids separation will be discussed below under the subsection on suspended solids removal.

Specific Surface Area--

The derivative form of Equation 2 indicates that the rate of removal of organic material is directly proportional to the specific surface area of the media used.

$$\frac{dS}{dt} = -k_3A_vt \qquad (11)$$

This equation predicts that the specific surface area will have a strong effect on performance and suggests that the designer should attempt to use a media with as high a specific surface area as possible. There appear, however, to be two limitations to this concept.

The first concerns possible plugging of the media when a high specific surface area is used. Specific surface areas for plastic media generally range from 82 to 246 m^2/m^3 (25 to 75 ft^2/ft^3), although some companies manufacture media with even higher values. Associated with higher specific surface areas are smaller voids in the media which can become more easily plugged by developing biomass. Generally, for secondary treatment applications, the specific surface area should be less than 131 m^2/m^3 (40 ft^2/ft^3) unless prior pilot testing is undertaken to ensure that plugging will not occur. For applications such as separate-stage nitrification of secondary effluent, which involves very thin slime layers, higher specific surface areas can be used.

The second limitation also involves growth of the biomass within the filter and is, in fact, a phenomenon which has plugging as its extreme manifestation. As the slime layer in the media increases in thickness, the effective surface area may be decreased as small voids become filled with biomass. This effect will be more pronounced, of course, at high specific surface areas, and doubling the specific surface areas, therefore, may not double the removal rate. One of the most comprehensive studies involving trickling filtration with media of varying specific surface areas was described in two papers by Bruce and Merkens (19,20). They reported on 3-1/2 yr of pilot studies in Great Britain which evaluated six media ranging in specific surface from 39 to 220 m^2/m^3 (12 to 67 ft^2/ft^3). Four of the media were plastic module types; the other two were rock and blast furnace slag (both 39 m^2/m^3 or 12 ft^2/ft^3). Total BOD_5 was measured on both the influent and effluent from the pilot clarifiers. All of the pilot biofilters were 2.1 m (7.0 ft) deep, and organic loadings over the period of study ranged from 0.64 to 4.5 kg BOD_5/m^3/day (40 to 280 lb/1,000 ft^3/day). The range for any particular media type may have been less.

The effect of specific surface area on performance can be evaluated by rewriting Equation 2 as follows:

$$\frac{S_e}{S_o} = e^{-kA_V^p D^m/q^n} \tag{12}$$

The exponent p can be evaluated to determine the effect of A on performance. Assuming n = 0.67 and given that D = 2.1 m (7.0 ft) for all the data:

$$\frac{S_e}{S_o} = e^{-kD^m A_V^p/q^{0.67}} \tag{13}$$

Then:

$$\ln \frac{S_e}{S_o} = \frac{-kD^m A_v^p}{q^{0.67}} \tag{14}$$

$$q^{0.67} \ln \frac{S_e}{S_o} = -kD^m A_v^p \tag{15}$$

Plotting $q^{0.67} \ln(S_e/S_o)$ vs. A_v on log-log coordinates will allow the exponent p to be evaluated. Shown on Figure 41 is such a plot for the data obtained by Bruce and Merkens (20). The slope of the line drawn through the plotted points represents the exponent p. From Figure 41, a value of approximately 0.7 is obtained. Figure 41 indicates that while increased specific surface area may be expected to lead to improved performance, the dependency is not as strong as Equation 11 suggests.

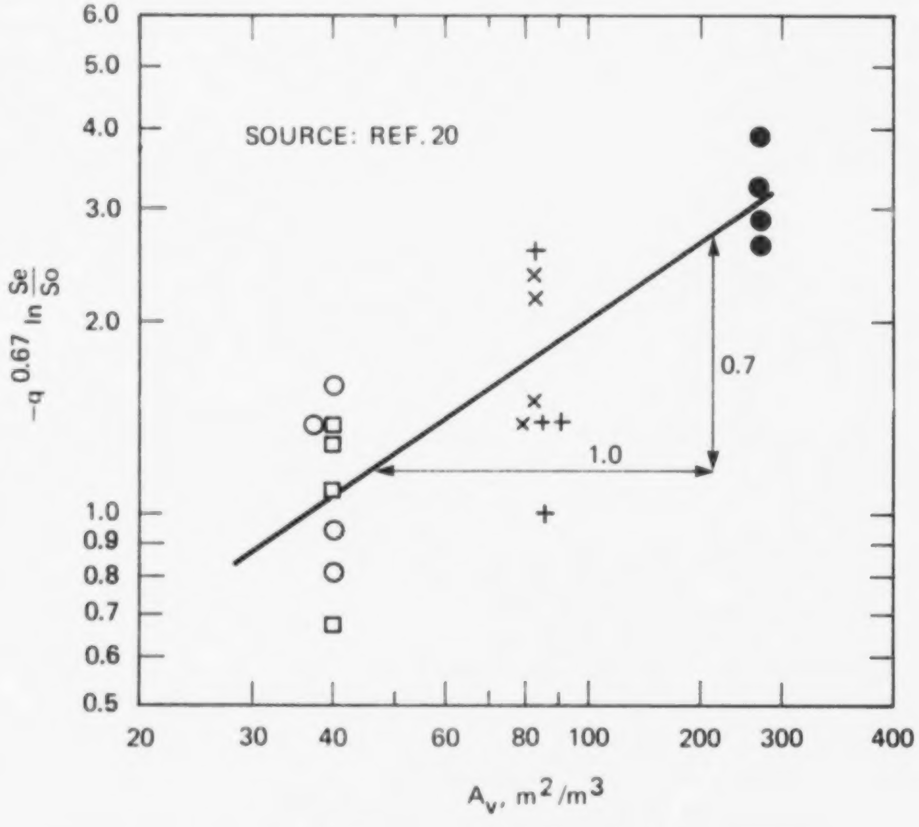


Figure 41. Effect of specific surface area on BOD_5 removal.

Data from the medium with the highest specific surface area of those tested (Cloisonyle at 220 m^2/m^3 or 67 ft^2/ft^3) w ere not used in determining the slope. The data developed by Bruce and Merkens and by Hutchison (discussed below) showed that for Cloisonyle, which consists of vertical tubes extending the entire depth of the filter, performance fell far below that which would be expected from a medium with such a high specific surface area. Measurement of contact times for the various media showed that Cloisonyle produced contact times which were much lower than expected for its high specific surface area (19). A strong correlation between specific surface area and contact time was shown for the other media tested.

Hutchison, in pilot studies at Auckland, New Zealand, tested four types of synthetic media, with specific surface areas of 89, 89, 118, and 220 m^2/m^3 (27, 27,36, and 67 ft^2/ft^3) (21). While improved soluble BOD_5 removal resulted from increasing the specific surface area from 89 to 118 m^2/m^3 (27 to 36 ft^2/ft^3, increasing the specific surface area to 220 m^2/m^3 (67 ft^2/ft^3) (Cloisonyle) resulted in deteriorating performance. These results are similar to these reported by Bruce and Merkens.

In pilot studies on secondary treatment processes for the Municipality of Metropolitan Seattle (22), high-specific-surface-area media (138 m^2/m^3 and 223 m^2/m^3 or 42 ft^2/ft^3 and 68 ft^2/ft^3, both manufactured by Munters) of the modular type was employed in the belief that high BOD_5 removals would be obtained. The clearances between the 223 m^2/m^3 (68 ft^2/ft^3) media sheets were too small, however, and the pilot tower failed due to plugging. The tower with the 138 m^2/m^3 (42 ft^2/ft^3) media did not fail, but removal and inspection of the media showed a buildup of slime which might have eventually led to plugging.

A random-packed media with a specific surface area of 95 m^2/m^3 (29 ft^2/ft^3) was also employed at Seattle, and it also failed due to plugging. The reason for the plugging was that the small void spaces did not allow sloughing of the biomass.

During the second phase of the Seattle study, two modular media designs were evaluated in parallel tests (22). The first design was a medium with a constant specific surface area of 89 m^2/m^3 (27 ft^2/ft^3) with a total media depth of 6.7 m (22 ft). The second design used a 89 m^2/m^3 (27 ft^2/ft^3) medium at the top of the tower, increasing to 138 m^2/m^3 (42 ft^2/ft^3) at the bottom of the tower. It was believed that plugging could be avoided by using a medium with larger void spaces at the top of the tower where biomass growth is greatest. In the lower part of the tower, where the slime thickness is less and plugging would not be expected to occur, a higher specific surface area should aid performance. Preliminary analysis shows little difference in performance between the two designs. In the loading range of 0.4 to 0.8 kg soluble BOD_5/m^3/day (25 to 50 lb/1,000 ft^3/day), effluent soluble BOD_5 concentrations ranged from about 7 to 15 mg/l. The only apparent advantage of the graded media was a more consistent performance with less scatter to the data, but there are signs that the graded media also suffers from occasional temporary plugging problems.

Also during the second phase of the Seattle pilot study, an evaluation was made of a random media with a specific surface area of 98 m^2/m^3 (30 ft^2/ft^3), which is claimed by the manufacturer to possess a geometry for which plugging is not a problem. During the first 3 mo of operation, this media was used without apparent problems.

The plugging which has occurred at Seattle may be peculiar to that set of circumstances; much of the BOD_5 removal and consequent biomass growth has occurred in the top portion of the towers. Thus, plugging might be more likely to occur.

In summary, attempting to obtain improved secondary treatment performance by using a media with a very high specific surface area (greater than approximately 115 m^2/m^3 to 164 m^2/m^3 or 35 to 50 ft^2/ft^3) may prove futile. The expected performance may not be achieved, and a total breakdown due to plugging may occur.

High-specific-surface-area media (greater than 131 m^2/m^3 or 40 ft^2/ft^3) do have an important role to play in wastewater treatment, particularly in separate-stage nitrification applications and in two-stage secondary treatment processes, but they should probably not be used in single-stage secondary treatment applications without pilot testing to predict performance.

Media Depth--

Economic considerations usually result in plastic media biofilters being constructed at depths (6.1 to 9.1 m or 20 to 30 ft) much greater than rock media filters (1.2 to 2.4 m or 4 to 8 ft). The appearance of D in Equation 2 may be misleading, however, in regard to the importance of depth as a design parameter for obtaining a specified level of performance. Consider the basic design equation as written below:

$$\frac{S_e}{S_o} = e^{-k_1 D^m / q^n} \qquad (16)$$

Substituting Q/A for q yields:

$$\frac{S_e}{S_o} = e^{-k_1 D^m A^n / Q^n} \qquad (17)$$

where:

Q = influent flow (excluding recycle), gpm

A = biofilter cross-sectional area, ft^2

If $m = n$:

$$\frac{S_e}{S_o} = e^{-k_1 (DA)^n / Q^n} = e^{-k_1 (V/Q)^n} \qquad (18)$$

where:

V = media volume, ft^3

Equation 18 is closely related to the traditional loading parameter of $kg/m^3/day$ (lb BOD_5/1,000 ft^3/day). The media volume thus becomes the chief design parameter once the media specific surface area, influent flow, influent BOD_5 level, and required effluent quality are known.

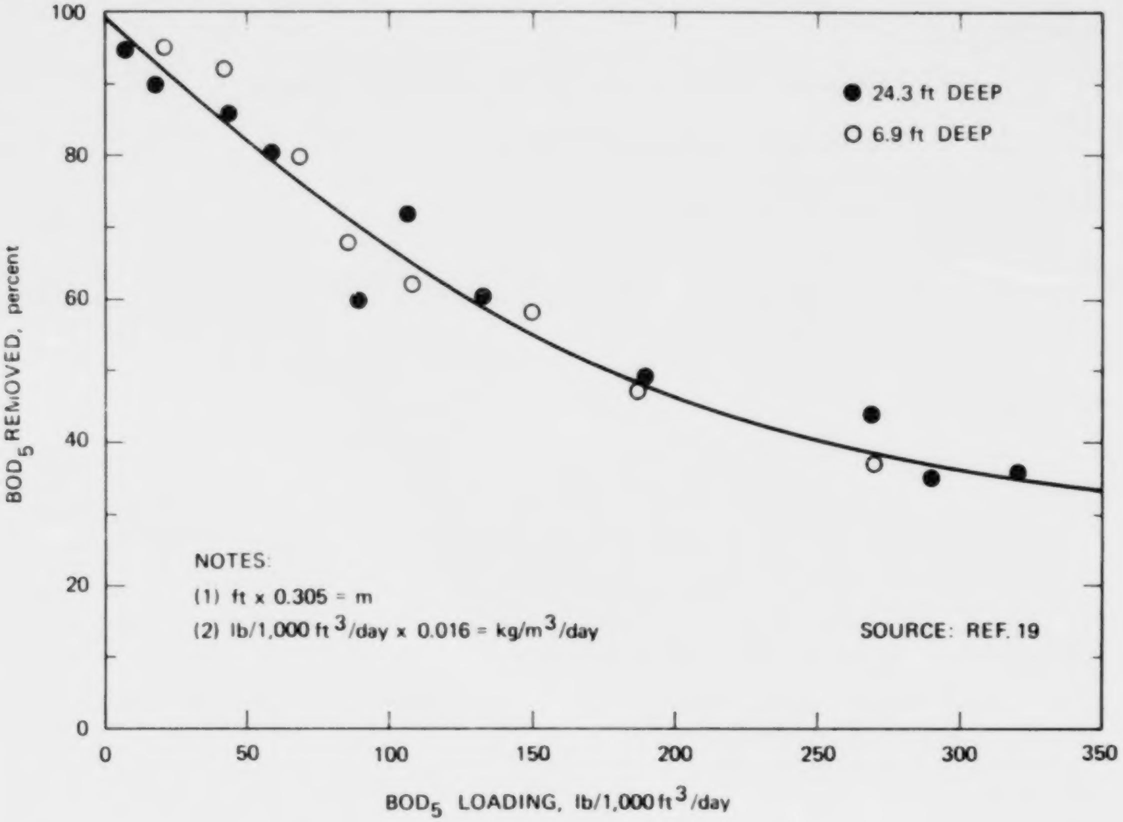
Even when $m \neq n$, available experimental evidence indicates that volumetric organic loading is a better indicator of BOD_5 removal than tower depth (19,22,23). Shown in Figure 42 is a plot of BOD_5 removal and organic loading for two plastic media trickling filters with media depths of 7.4 m (24.3 ft) and 2.1 m (6.9 ft) (19). Removal is based on total influent BOD_5 and total effluent BOD_5 after settling. Over a wide range of loadings, there is no discernible difference in performance between the two filters.

This point is stressed because normally cited values for m in Equation 16 are greater than those normally given for n. With such values, Equation 16 predicts that deep towers will perform better than shallow towers at the same media volumes. Most of the available evidence does not support this conclusion, however. The normal range of depths usually found is about 4.6 to 9.1 m (15 to 30 ft), with 6.1 to 7.6 m (20 to 25 ft) most common.

Hydraulic Loading and Recirculation--

Hydraulic loading is also a parameter whose importance can be overestimated from inspection of the Velz equation, where it appears as an independent variable.

Once the design organic loading is established, the resultant total hydraulic loading (including recycle) should be inspected to determine whether it falls between recommended minimum and maximum values and to ensure that recirculation is adequate.



NOTES:

(1) ft × 0.305 = m

(2) lb/1,000 ft^3/day × 0.016 = kg/m^3/day

SOURCE: REF. 19

Figure 42. BOD$_5$ removal and organic loading at two biofilter depths.

A minimum total hydraulic loading is recommended by each media manufacturer to ensure complete wetting of the media surface which, in turn, assures that the entire media surface contributes to biological treatment. A minimum application rate also helps prevent freezing in cold climates. The "rule-of-thumb" recommended minimum for B. F. Goodrich's Vinyl Core and Envirotech's Surface, for example, is 0.031 m^3/min/m^2 (0.75 gpm/ft^2).

Section 7 described how performance at Stockton was improved by increasing the total hydraulic loading (by increasing recirculation) from about 0.024 to 0.031 m^3/min/m^3 (0.6 to 0.75 gpm/ft^2) in conjunction with increasing the forced draft ventilation. It is uncertain which of these actions had a beneficial effect, but both nitrification and BOD$_5$ removal improved substantially after the operational modifications were made.

Exceeding recommended maximum hydraulic loadings will not normally occur in applications where a moderate or high degree of treatment is provided. Exceptions may occur in roughing applications, such as where a trickling filter precedes an activated sludge unit. Total hydraulic loadings of 0.16 to 0.24 $m^3/min/m^2$ (4.0 to 6.0 gpm/ft^2) have been used with good results, but the upper limit on allowable hydraulic loading is uncertain.

Benefits to be attained from recirculation with plastic media are intangible, but experience has indicated that, particularly where nitrification is desired, provision of recirculation can result in more stable and improved performance. The Velz equation (Equation 2) can be modified to incorporate the effect of recirculation on predicted BOD_5 removal. This calculated difference is in most cases negligible, and the Velz equation should not be used to attempt to predict the effect of recirculation.

In Section 7, it was indicated that recirculation can increase the contact time of the wastewater in the filter. For example, the "fall velocity" of wastewater through the media will be less than double its original value if the total hydraulic loading is doubled through an increase in the recirculation rate. As contact time may affect nitrification, recirculation may be an important factor in attaining the desired nitrification performance.

Normally, meeting the recommended minimum total hydraulic loading will require high recirculation ratios where nitrification (either combined or separate-stage) is practiced. For carbonaceous oxidation alone, a recirculation ratio of 1:1 is probably a good "rule-of-thumb."

Summary--

The widespread use of the Velz equation and similar relationships make it almost mandatory to rely on them for design purposes. More rational design procedures such as that developed by Williamson and McCarty (10) are difficult to utilize, and the semi-empirical methods will continue to be relied upon for the foreseeable future.

The key to using empirical design methods sensibly is to avoid extrapolation of variables (e.g., BOD_5 removal, media depth, specific surface area) beyond values for which reliable operational and performance data are available. If unusual circumstances are envisioned, pilot studies may be used to develop reliable information on expected performance.

Nitrification

While a great deal of effort has been expended toward defining the carbonaceous BOD_5 removal characteristics of plastic media biofiltration, much less information is available on the ability of this process to nitrify. A few studies (24,25,26,27,) have been carried out on separate-stage nitrification of secondary effluent, but this report and the 1972 Stockton pilot study (5,6) appear to be the most substantive investigations undertaken on combined carbon oxidation- nitrification in plastic media biofilters. Nevertheless, available information on nitrification kinetics, coupled with data obtained from the activated sludge process, rotating biological discs, and rock trickling filters, allows presentation of an empirical basis for design and provides insight into the design and operational parameters which apply to nitrification in plastic media trickling filtration. For an in-depth review of nitrification process kinetics and the factors which can affect nitrification performance, the reader is referred to the U.S. Environmental Protection Agency Technology Transfer publication, Process Design Manual for Nitrogen Control (14).

This subsection is divided into two parts. In the first part, a review of available information on design of separate-stage nitrification is discussed. Secondly, design and operating criteria for combined carbon oxidation-nitrification are presented.

Separate Stage Nitrification--

Nitrification in the trickling filter process (or any other biological treatment process) can be classified as either separate-stage nitrification or combined carbon oxidation-nitrification, which is used at Stockton. Combined carbon oxidation-nitrification processes have a low population of nitrifiers due to a high ratio of BOD_5 to total Kjeldahl nitrogen (TKN) in the influent (14). Separate-stage nitrification has a lower BOD_5 load relative to the influent ammonia nitrogen load. As a result, a higher fraction of nitrifiers is obtained, resulting in higher rates of nitrification. To achieve separate-stage nitrification, pretreatment (chemical primary or biological secondary treatment) is required to lower the organic load or the BOD_5/TKN ratio.

An illustration of the effect of the BOD_5/TKN ratio on nitrification rates in an attached growth reactor is presented in Figure 43 (28). Interestingly, a small amount of BOD_5 (about 10 mg/l) was found to enhance the nitrification rate.

In general, combined carbon oxidation-systems have BOD_5/TKN ratios greater than 5.0, and separate-stage systems have BOD_5/TKN ratios less than 3.0. In combined systems, the nitrogenous oxygen demand (NOD) generally accounts for less than 40 percent of the total oxygen demand. In separate-stage systems, NOD normally accounts for 60 to 70 percent or more of the total demand.

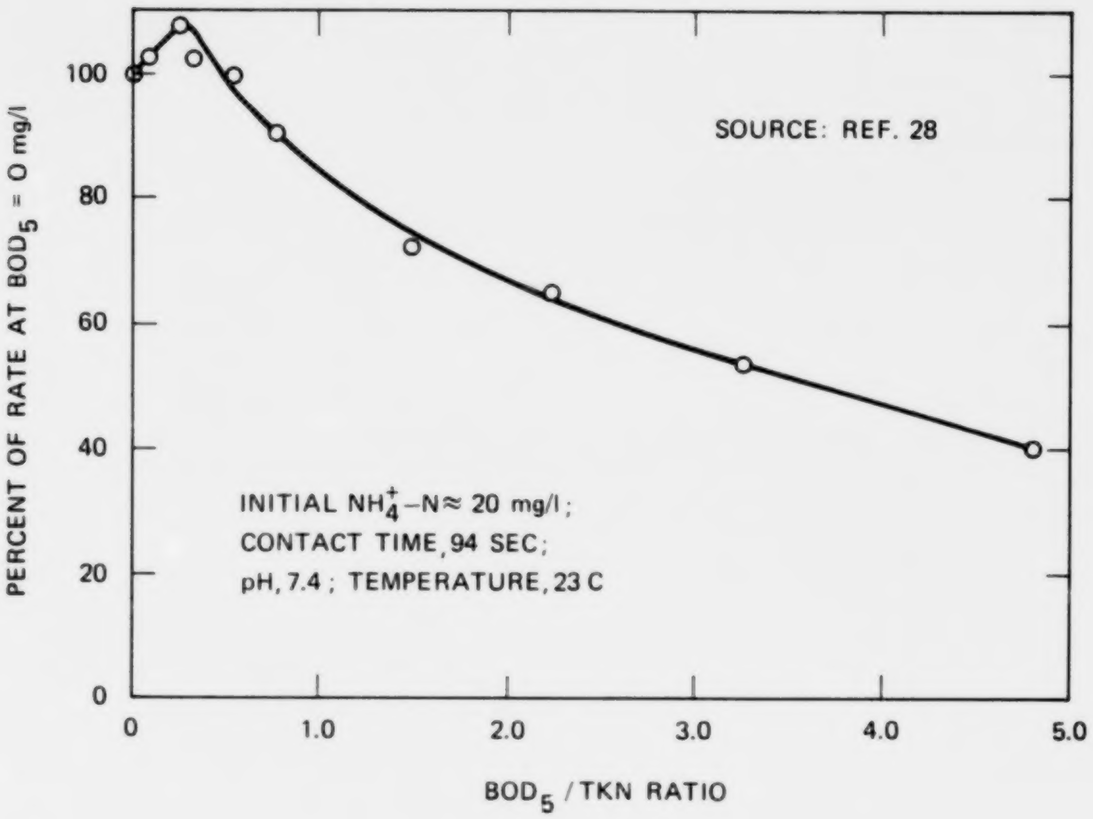
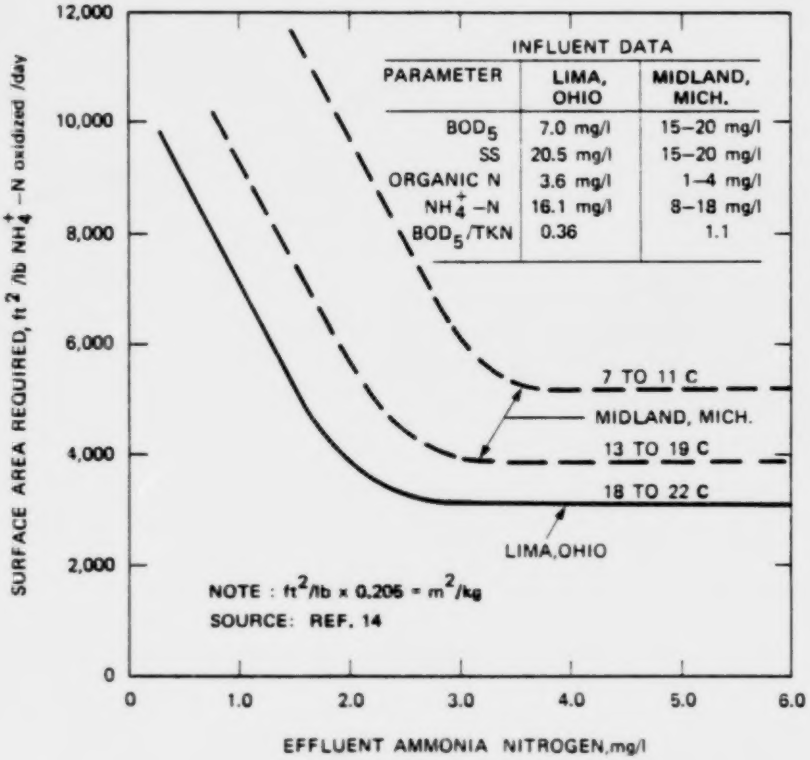


Figure 43. Effect of BOD_5/TKN ratio on nitrification rate.

In separate-stage nitrification applications, the nitrification rate is proportional to the surface area exposed to the liquid (10,30). In other words, when all other parameters are held constant, the loading/performance relationship can be expected to be related to the media surface area rather than volume.

Very little biological film development occurs in separate-stage applications (24,27). Consequently, plugging of voids and ponding is less of a concern than in cases where carbonaceous BOD_5 is being removed. One advantage is that a medium of high specific surface area can be used, up to 230 m^2/m^3 (70 ft^2/ft^3) or higher. Another result of the small amount of biological growth is the reduced effluent suspended solids level. In some cases, subsequent solids separation steps may not be needed.

Loading Criteria--Data from two pilot studies, at Midland, Michigan (24,25), and at Lima, Ohio (26), were used to develop the loading/performance curves shown in Figure 44. The surface area required, in terms of ft^2/lb ammonia nitrogen oxidized/day, is plotted against desired ammonia nitrogen effluent concentration. Data are plotted for three temperature ranges, exhibiting the strong dependence of nitrification rate on wastewater temperature.



INFLUENT DATA

PARAMETER	LIMA, OHIO	MIDLAND, MICH.
BOD_5	7.0 mg/l	15–20 mg/l
SS	20.5 mg/l	15–20 mg/l
ORGANIC N	3.6 mg/l	1–4 mg/l
NH_4^+–N	16.1 mg/l	8–18 mg/l
BOD_5/TKN	0.36	1.1

NOTE : ft^2/lb × 0.205 = m^2/kg

SOURCE: REF. 14

Figure 44. Separate-stage nitrification performance.

A key point indicated by Figure 44 is that to produce effluent ammonia nitrogen concentrations below about 3.0 mg/l, the required surface area increases dramatically. For example, to achieve an effluent concentration of 3.0 mg/l in the 13 C to 19 C temperature range, a surface area of about 820 m^2/kg (4,000 ft^2/lb) ammonia nitrogen oxidized is indicated in Figure 44. To reduce the effluent concentration to 1.0 mg/l, a surface area of 2,050 m^2/kg (10,000 ft^2/lb) ammonia nitrogen/day, a 250 percent increase, is required. Thus, 3.0 mg/l effluent ammonia nitrogen can be considered the practical limit for separate-stage nitrification in plastic media trickling filters.

The BOD_5/TKN ratios for these two studies were very low, 1.1 for Midland, Michigan, and 0.36 for Lima, Ohio.

Pilot studies involving nitrification of stabilization pond effluent (27) at Sunnyvale, California, revealed that about 40 percent more surface area was required than at Midland, Michigan, to achieve the same effluent ammonia nitrogen levels at similar operating temperatures. It was hypothesized that algae trapped in the biofilter were eventually oxidized, which increased the fraction of heterotrophic organisms in the bacterial film. This indicates that where BOD_5/TKN ratios are higher, i.e., nearer 3.0, greater surface areas may be needed to achieve the required degree of nitrification.

Because trickling filters, like any other process used for nitrification, are affected by diurnal variations in nitrogen load, this variation should be accounted for in applying Figure 44. The amount of surface area determined from Figure 44 for average loading conditions can be multiplied by the ammonia nitrogen peaking factor to establish a design surface area. An alternative approach would be provision of flow equalization.

Organic Nitrogen Removal--While very high ammonia nitrogen removals can be attained with plastic media biofilters, organic nitrogen removals are usually quite low. It was noted in Section 7 that for the combined carbon oxidation-nitrification system at Stockton, organic nitrogen removals were less than 50 percent. At Midland, Michigan, influent organic nitrogen concentrations were low, ranging from about 1 to 4 mg/l. Removals were also low, generally 40 percent or less.

Effect of Recirculation--An analysis of the Midland, Michigan and Lima, Ohio data has led to the conclusion that while recirculation improved nitrification efficiency only marginally, the periods with recirculation demonstrated greater consistency than those with no recirculation (24,25). This conclusion, together with improvement seen with recirculation in rock trickling filter combined carbon oxidation-nitrification (14), leads to a general recommendation for provision of recirculation. A 1:1 recirculation ratio at average dry weather flow is considered adequate for most applications.

Effluent Clarification--Because the organisms are attached to the media and because the net organism growth is small, effluent clarification steps are not required in all cases. In the Midland, Michigan study, it was found that effluent suspended solids levels were approximately equal to influent concentrations (10-30 mg/l) (25) when influent BOD_5 levels were in the 15-20 mg/l range. When influent BOD_5 concentrations were increased, effluent solids rose to about 60 mg/l. The use of a gravity clarifier reduced this to about 20 mg/l, and subsequent multi-media filtration further reduced suspended solids to about 5 mg/l. In some cases, filtration alone may be substituted for gravity clarification.

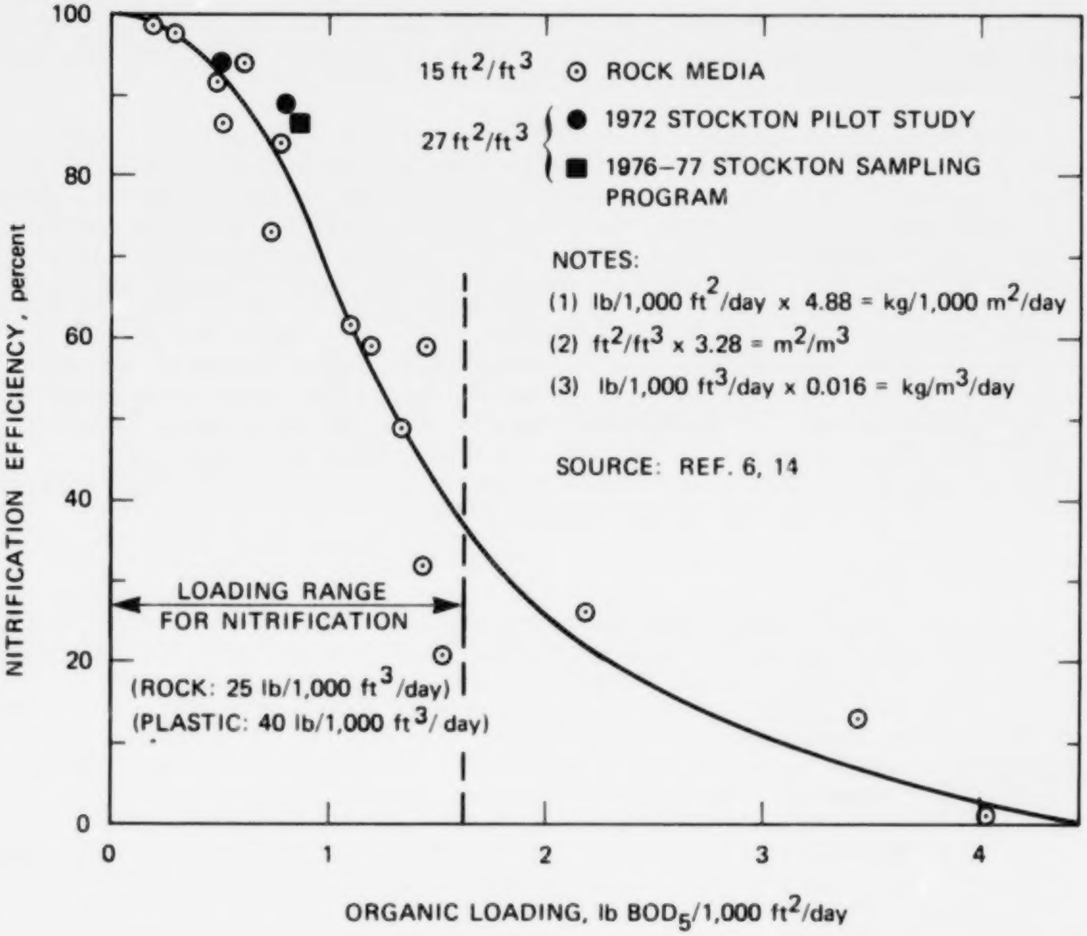
Combined Carbon Oxidation-Nitrification--

Presentation of design concepts for combined carbon oxidation-nitrification in plastic media biofilters suffers from both a lack of operating data and from the absence of any developed kinetic theory comparable to that which has been developed for the activated sludge process. As previously noted, the 1972 Stockton pilot study plus the sampling program undertaken for the present investigation appear to be the only studies conducted specifically on combined carbon oxidation-nitrification plastic media trickling filters. The biofilter theory of Williamson and McCarty may provide insight into design concepts but is difficult to apply to design situations (10).

Performance-Loading Relationships--Much work, at least in terms of data collection, has been done on nitrification in rock media, dating back to the NRC studies during World War II (4), which found that rock media trickling filters used for secondary treatment were capable of producing nitrified effluents when organic loadings were low. They stated that nitrification occurred only when organic loadings were less than 0.40 kg BOD_5/m^3/day (25 lb/1,000 ft^3/day); the lowest loadings produced the highest effluent nitrate nitrogen concentrations. To obtain a highly nitrified effluent with rock media filters, the loading should be kept below 0.2 kg/m^3/day (12 lb/1,000 ft^3/day).

If it is assumed that nitrification efficiency is a function of media specific surface area, data from rock media and plastic media plants can be compared on that basis. To that end, Figure 45 was prepared which shows nitrification efficiency (ammonia nitrogen removal) plotted against organic loading. Data for rock media biofilters with recirculation were taken from the U.S. Environmental Protection Agency Technology Transfer publication, Process Design Manual for Nitrogen Control (14). An assumed specific surface area of 49 m^2/m^3 (15 ft^2/ft^3) was used for the rock media. Data for plastic media are taken from two loading conditions of the 1972 Stockton pilot study and from the latter portion of the 1976-77 sampling program at Stockton, after the operational modifications to improve performance were made.

Figure 45 has been developed for illustration purposes only and should not be used for design. A serious drawback, for example, is the exclusion of temperature effect from the plot. Nevertheless, several conclusions can be drawn. First, although the loading range for plastic media is limited, there is good agreement between data for the two media types. Second, the maximum allowable loading cited by the NRC appears to be correct. The measured nitrification efficiencies at loadings greater than 8.3 kg BOD_5/1,000 m^2/day (1.7 lb/ 1,000 ft^2/day) are probably due not to the conversion of ammonia nitrogen to the nitrate from but to the assimilation of ammonia nitrogen bacterial cells produced in the course of carbonaceous BOD_5 removal. Nitrification efficiency is normally expressed as percentage ammonia reduction, even though nitrification may not be the sole mechanism responsible for the measured removal.



NOTES:

(1) lb/1,000 ft^2/day x 4.88 = kg/1,000 m^2/day

(2) ft^2/ft^3 x 3.28 = m^2/m^3

(3) lb/1,000 ft^3/day x 0.016 = kg/m^3/day

SOURCE: REF. 6, 14

Figure 45. Combined carbon oxidation-nitrification performance.

Figure 45 shows that, as expected, nitrification in combined systems is strongly dependent on organic loading. At loadings below 4.9 kg BOD_5/1,000 m^2/day (1.0 lb/1,000 ft^2/day), nitrification efficiencies above 70 percent can be expected and loadings of less than about 2.4 kg/1,000 m^2/day (0.5 lb/1,000 ft^2/day) can produce ammonia nitrogen removals of more than 90 percent. At loadings above 4.9 kg/1,000 m^2/day (1.0 lb/ 1,000 ft^2/day), performance drops off rapidly as the fraction of nitrifying organisms decreases.

Organic Nitrogen Removal--Even with high ammonia nitrogen reductions, organic nitrogen removals will be low. The contact time is apparently not sufficiently long to allow completion of the reactions converting organic nitrogen to ammonia nitrogen. Organic nitrogen removal during the 1972 Stockton pilot study was about 25 percent; during the sampling program at the full-scale plant, it was less than 50 percent.

Hydraulic Loading and Recirculation--In order to achieve low organic loadings and maintain the minimum hydraulic loading for "wetting" of the media surface, a high recirculation ratio is required. Minimum hydraulic loadings recommended by media manufacturers are generally in the range of 0.031 to 0.041 $m^3/min/m^2$ (0.75 to 1.0 gpm/ft^2). To maintain a hydraulic loading of 0.031 $m^3/min/m^2$ (0.75 gpm/ft^2) with an organic loading of 0.32 kg BOD_5/m^3/day (20 lb/1,000 ft^3/day), an influent BOD_5 concentration of 150 mg/l, and a media depth of 6.1 m (20 ft), a recirculation ratio of 2.4:1 will be required. Poor performance at Stockton during the period when hydraulic loadings were below the recommended minimum wetting rate lends strong support for providing adequate recirculation capacity in the design of plastic media facilities.

Oxygen Transfer

Most substrate removal models for biofilters and other attached-film reactors have assumed that the removal process is limited by bacterial growth rate. Recent papers by Mehta, Kingsbury and Davis (29). Schroeder and Tchobanoglous (30), and Williamson and McCarty (10) have attempted to demonstrate, however, that under certain conditions, oxygen transfer can limit BOD_5 removal and nitrification.

The Williamson and McCarty model predicts that, for attached growth systems, substrate removal becomes limited by dissolved oxygen (DO) concentrations when the soluble BOD_5 exposed to the film exceeds about 40 mg/l. This condition can occur with strong municipal or industrial wastewaters. For weak wastes, the untreated soluble BOD_5 may be lower than the 40 mg/l limit or the soluble BOD_5 may be reduced to 40 mg/l in the top few feet of the filter. In either case, oxygen transfer would not then be limiting.

Williamson and McCarty also developed a theory concerning nitrification and oxygen transfer. They predicted that the DO concentration to avoid oxygen flux limitations would have to be 2.7 times the ammonia nitrogen concentration. They noted that the two operational ways to overcome this limitation are to dilute the ammonia nitrogen by recirculation or to increase the DO level. The latter can be done by increasing the forced draft ventilation rate. It was noted in Section 7 that increasing the forced draft ventilation rate (which increased measured DO levels only marginally) and increased recirculation at Stockton resulted in significant improvement in nitrification performance.

Ventilation

Most media manufacturers indicate that as long as there is sufficient freedom for air to flow through the biofilter, forced draft ventilation is not normally required. Possible exceptions are where strong industrial or combined wastes are being treated, as at Stockton. Also, in very cold climates, a means of restricting air flow may be desirable to prevent excessive cooling of the wastewater.

TABLE 29. PARAMETERS AFFECTING AIR FLOW THROUGH BIOFILTERS

Number	Driving force	Resulting air flow direction
1	Heat transfer: water warms or cools air	up or down
2	Increased relative humidity of air in tower	up
3	Wind blowing across top of tower (whistle effect)	Up (usually) or down
4	O_2 partial pressure decrease; CO_2 partial pressure increase	down
5	Downward movement of water "pulling" air	down

Natural forces cannot be counted upon, however, to provide air flow through the filters under all circumstances. Shown in Table 29 are five factors which can affect air flow through a biofilter, along with the direction of flow which normally results. Although unlikely, situations can occur where the net force directing air flow through the tower is zero and no movement occurs. In pilot biofilter studies at Seattle, Washington (22), both upward and downward air flows were observed. The Seattle climate exhibits moderate temperatures and high humidities, meaning that there is little change in air temperatures or humidity through the tower (items 1 and 2 in Table 29). Under such conditions, provision of forced draft ventilation might be desirable to ensure adequate air flow.

Clarification

A commonly voiced criticism of the trickling filtration process is that it cannot be counted upon to produce effluents with low suspended solids concentrations. A specific concern is the 30-mg/l monthly average suspended solids concentration as mandated by federal secondary treatment guidelines. In this subsection, four possible methods of improving clarification are discussed: (1) reduced secondary clarifier loadings, (2) tube settlers, (3) chemical addition, and (4) rapid sand filtration. The first two methods can be expected to produce effluent suspended solids concentrations in the 20- to 30-mg/l range. The second two methods are required to reduce effluent suspended solids concentrations below 15 mg/l.

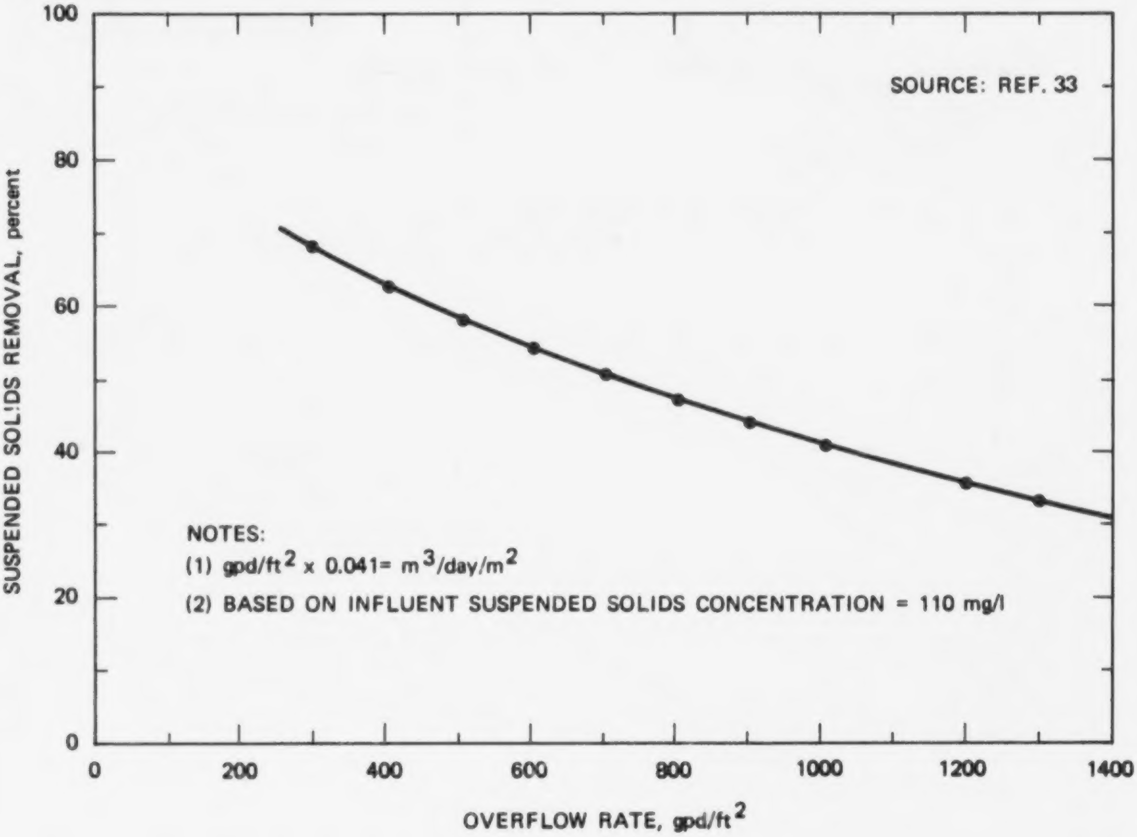
Reduced Secondary Clarifier Loadings--

Historically, trickling filter secondary clarifiers have been designed with overflow rates of 33 to 49 $m^3/day/m^2$ (800 to 1,200 gpd/ft^2) (similar to those for primary clarifiers), but performance objectives in the past have been much different from those of today. Design effluent concentrations were usually around 40 to 80 mg/l BOD_5 and suspended solids; loadings to both the biofilters and secondary clarifiers were set to meet these objectives. Recently, although much effort has been directed to determining the loading-removal relationships for plastic media biofilters (with the purpose of providing improved performance), much less work has been done on the contribution of secondary clarification to overall performance.

Some evidence exists, however, to indicate that lower hydraulic loadings can result in sufficiently improved performance to meet the 30-30 mg/l secondary treatment requirements for BOD_5 and suspended solids (31,32). Shown in Figure 46 is a graph of secondary clarifier performance vs. overflow rate for a trickling filter plant (31). This study, undertaken by Brown et al. to determine methods of improving trickling filter performance, showed that percentage suspended solids removal increased from about 30 percent at 57 $m^3/day/m^2$ (1,400 gpd/ft^2) to over 60 percent at 16 $m^3/day/m^2$ (400 gpd/ft^2). Figure 46 clearly illustrates the relationship between loading and performance. As a result of the study, the authors recommended that trickling filter secondary clarifiers be designed with average dry weather overflow rates of around 20 $m^3/day/m^2$ (500 gpd/ft^2) (32). The data developed in that study are strong evidence that continued use of traditional design parameters for biofilter secondary clarifiers may be improper when low effluent BOD_5 and suspended solids concentrations are sought.

Tube Settlers--

Pilot studies on plastic media trickling filters at the Municipality of Metropolitan Seattle have provided evidence that tube settlers can greatly aid secondary clarifier performance (22). Tube settlers are groups of 5 cm (2 in.) square channels or tubes constructed in module form to promote improved settling by creating laminar flow and reducing particle settling distance. A schematic diagram of tube settler operation is shown in Figure 47. The steep slope of the tube settlers (60 degrees) promotes gravity drainage of the settled solids countercurrent to the flow. Normally, only a portion of the clarifier surface is covered.

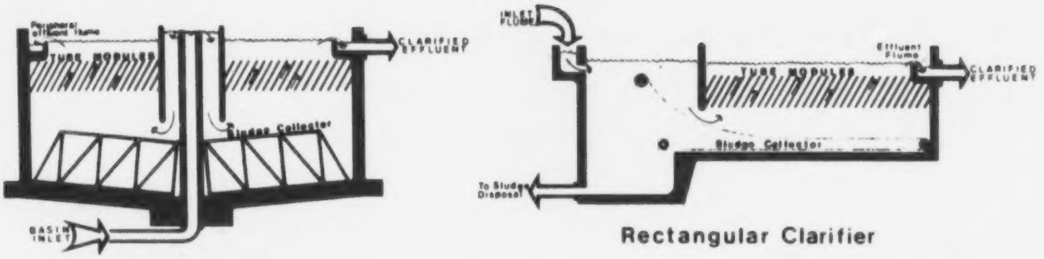


NOTES:
(1) gpd/ft^2 x 0.041= m^3/day/m^2
(2) BASED ON INFLUENT SUSPENDED SOLIDS CONCENTRATION = 110 mg/l

Figure 46. **Effect of overflow rate on trickling filter secondary clarification performance.**

The effect of tube settlers on performance in the Seattle pilot studies is depicted in Figure 48, which compares the improvement achieved by the use of tube settlers at increasing amount of surface coverage. It was concluded that there was almost no effect on performance at the two lowest coverages, 10 and 15 percent. At 40 percent coverage, effluent suspended solids concentrations averaged less than 30 mg/l at all solids loadings.

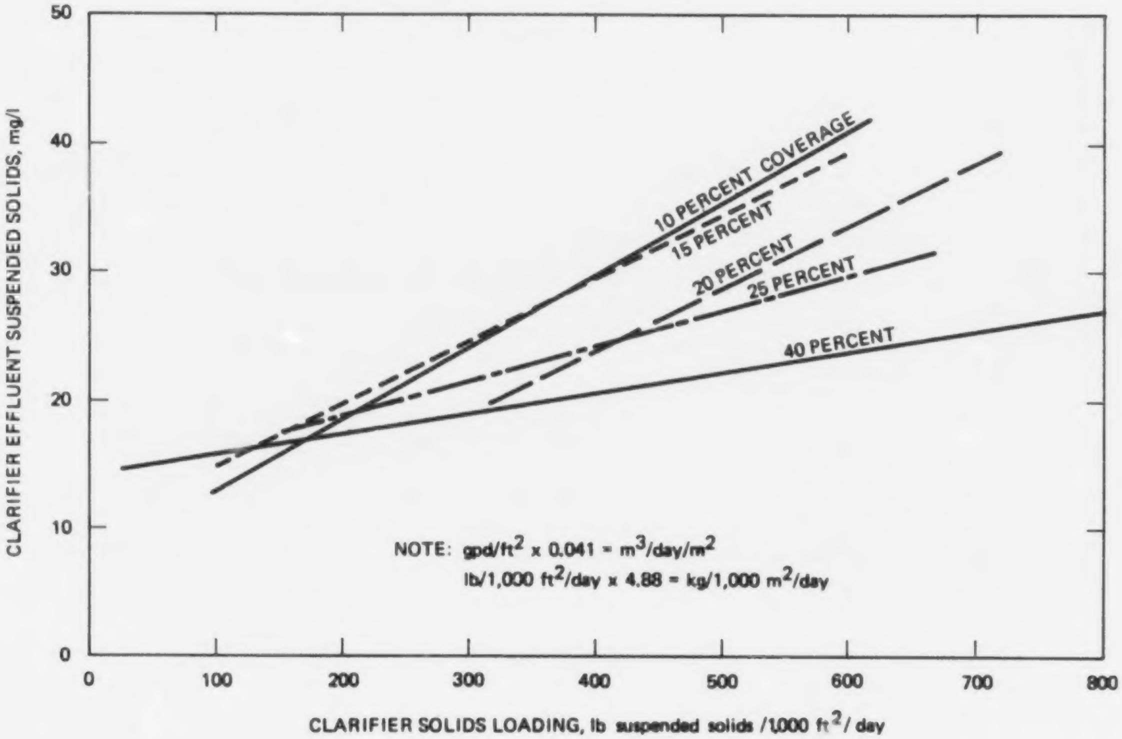
It was concluded that for the conditions encountered at Seattle, the maximum removal limits for secondary clarifiers equipped with tube settlers are 10-15 mg/l suspended solids and that practical concentration limits will be somewhat higher than this.



Circular Clarifier

Rectangular Clarifier

Figure 47. Tube settler schematic (courtesy Neptune-Microfloc).



NOTE: gpd/ft^2 x 0.041 = m^3/day/m^2
lb/1,000 ft^2/day x 4.88 = kg/1,000 m^2/day

Figure 48. Effect of tube settlers at Seattle, Washington.

Chemical Precipitation--

Aluminum or ferric salts or lime can be added to clarifiers solely for the purpose of enhancing suspended solids removal. Although capital costs for chemical addition facilities are minimal, operating expenses will increase significantly because of chemical costs; solids handling costs will also increase significantly. These drawbacks make it unlikely that chemical addition will be a cost-effective method of reducing suspended solids levels unless other objectives such as phosphorus removal also exist.

Information on design considerations for chemical addition is available in the U.S. Environmental Protection Agency Technology Transfer publication, Process Design Manual for Phosphorus Removal (33).

Filtration--

Dual-media or rapid sand filtration can also be utilized to reduce suspended solids levels from biofiltration secondary clarifiers. Granular media filtration is particularly applicable when discharge requirements specify very low effluent suspended solids concentrations, 5 to 15 mg/l. Dual-media filtration of secondary effluent will be used at Stockton during the November 15-July 15 period (noncanning season) to meet 10 mg/l BOD_5 and suspended solids effluent limitations.

Design information on wastewater filtration can be obtained from two U.S. Environmental Protection Agency Technology Transfer publications: the Process Design Manual for Suspended Solids Removal (34) and the seminar publication, "Wastewater Filtration: Design Considerations" (35).

Solids Production

Information presented in Section 7 (Table 22) showed a total secondary system solids production of 0.83 kg TSS produced/kg BOD_5 removed over the course of the sampling program at Stockton. Production decreased during the last portion of the sampling program, perhaps due to the increased air supply. For the last 5 mo of the study, production averaged 0.75 kg TSS produced/kg BOD_5 removed. Benjes (9) cites a typical total solids trickling filter system production as 0.67 kg TSS/kg BOD_5 removed.

Waste solids production, which excludes suspended solids lost in the effluent, averaged 0.65 kg TSS/kg BOD_5 removed for the entire Stockton sampling program. For the last 5 mo, the average was 0.61 kg TSS/kg BOD_5 removed. A value cited by Benjes as typical is 0.45 kg TSS/kg BOD_5 removed.

PHYSICAL DESIGN

Physical design considerations include both general design principles for any filter design and specific problems which must be resolved in converting an existing filter. A careful analysis of the existing secondary treatment facilities for capacity, efficiency, and structural integrity will help the designer to select appropriate materials, to determine which structures can be reused, and to determine what additional facilities are needed. In most situations, the designer must ensure that the modifications can be constructed with a minimal interruption of the treatment processes. The modified system should have operational reliability and flexibility for future expansions or process additions. Operational ease and efficiency should be considered, particularly in the location of controls and parts which require periodic maintenance and repair.

In most upgrading situations, physical constraints will exist which limit the options available to the designer and which will result in a less optimal design than would result if an entirely new plant were being built. In many cases, overcoming these constraints will require considerable ingenuity on the part of the engineer. In extreme cases, the constraints may be so severe as to make filter conversion unwarranted; it may be more cost-effective to construct completely new biofilters.

Biofilters can be either circular or rectangular in shape. Since the rock media filters which would be considered for conversion to plastic media are normally circular, those design aspects peculiar to rectangular filters will not be discussed here. Further, most of the information presented will concern module-type media rather than the dumped type.

Conversion of a rock media filter to plastic media should be viewed in its relation to the rest of the secondary treatment facilities and to the other unit processes at the treatment plant. For example, modifications to the electrical system will probably be required for ventilation fans and additional pumps, the ventilation system may need to be modified substantially, and additional secondary clarification may be necessary. Additional solids handling facilities may be required by an increase in flow and the increase in solids production associated with greater BOD_5 removal.

Physical design considerations are discussed below for the major components of a trickling filter media conversion, including walls, influent piping and pumping, center column and distributor support, effluent collection and return, recirculation structure and pumping, media support system, ventilation, and overall plant configuration.

Walls

The primary functions of the walls in all biofilters are to contain the media, biomass, wastewater, and air; to protect the media from the wind; to insulate the wastewater and biomass from cold temperatures; and to provide an aesthetic covering.

In rectangular biofilters, the walls must support the wastewater distribution system. In some designs, the walls must also support a cover which functions as an air collection system. Most biofilter designs provide wind protection for the top of the media by allowing some freeboard between the top of the media and the top of the walls.

In converting an existing rock media filter to plastic media, maximizing use of the existing structure will influence wall design. The wall addition must blend architecturally with the existing wall, or it may be desirable to demolish the old wall and construct an entirely new wall. The foundation will have to support a much greater load; therefore, the adequacy of the existing foundation should be carefully checked. The designer should examine the soils report for the original structure if possible. The nature of the underlying soils and the condition and thickness of the existing foundation will determine what additional weight can be supported. The foundation will have to support the walls, the media, the biomass, the media support system, and the wastewater being treated. A design loading of approximately 400 kg/m^3 (25 lb/ft^3) plastic media can be used; this figure includes additional weight for a clogged filter.

A waterproof seal is necessary to prevent the wastewater from leaking through the walls. The concrete block walls of the Stockton filters are both lightweight and strong; the concrete blocks create a sealing problem, however. The porous blocks absorb the wastewater and transmit it through the wall. Expansion and contraction of the blocks may crack a sealer which is painted on the walls. The polyurethane sealer ultimately used at Stockton has proved sufficiently elastic to withstand the expansions and contractions. In a new plastic media filter for separate stage nitrification at Sunnyvale, California, a sheet liner of Hypalon (chlorosulfonated polyethylene) was placed inside the walls, held in place with a redwood framework. This was done to provide further assurances that leakage would not occur. The redwood frame also acted to prevent the liner from being cut by the sharp edges of the plastic media.

Other lightweight wall materials which have been used successfully in biofilters include corrugated PVC and polyester fiberglas, held in place with metal supports and wood. The wood, such as redwood, must be resistant to biological attack. The fiberglass should be opaque with a resin-rich surface. Corrugated panels must be overlapped, fitted with a gasket, and caulked at the seams. The fiberglas panels are probably more expensive than concrete block; however, they are waterproof and are easily installed and repaired. A filter with a corrugated PVC wall is shown in Figure 49.

A heavier, but very inexpensive, wall can be made of precast concrete tip-up panels. The precast panel design could be used with walls which are either polygonal or circular; a polygonal design would require removing the original low wall.

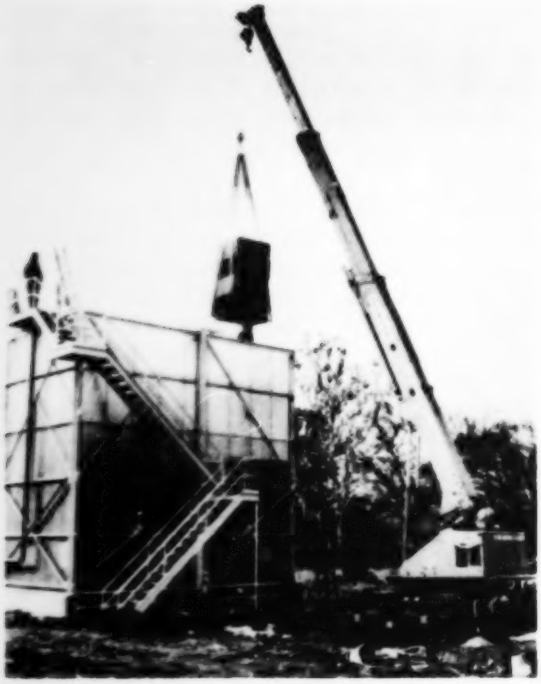


Figure 49. Corrugated PVC used for trickling filter walls. Shown here is a rectangular filter with media being installed (photograph courtesy B. F. Goodrich).

Influent Piping and Pumping

The influent piping system must be converted to accommodate the greater flow associated with plastic media filters. Many rock media systems are gravity fed; influent to the taller plastic media filters must be pumped. The original influent lines may be reusable; they should be carefully inspected, however, as the increased pressures of the pumping system may create leaks. Although the Stockton plans called for reusing the existing influent lines, much of the piping had to be repaired; inspection of the lines during construction revealed substantial hydrogen sulfide corrosion. Flexible connections were installed between the original piping and the piping in the new center column foundation in the Stockton filters to allow for differential settling between old and new structures.

The influent piping system should be designed or modified to give the system operational flexibility. Sufficient duplicate equipment should be supplied to continue treatment during maintenance or repair operations. Sluice gates or valves should be incorporated in the piping system to isolate parts which may require repairs. At the Lompoc, California, Regional Wastewater Reclamation Plant, supply pumps were sized to pump the peak wet weather flow to the filters with one pump out of service so that a nonfunctioning pump will shut down the filter. At the Stockton plant, where the downstream oxidation ponds provide a treatment buffer, each filter is served by a single influent line and supply pump. Regular maintenance work on the pump puts the corresponding filter out of operation. Also, each pump must be operated continuously, resulting in a shorter service life.

Piping should be designed to facilitate future expansions. If, for example, more biofilters will be added in the future, the piping system can be designed for the ultimate treatment configuration. That portion of the future piping system which connects to the present system can be constructed; the end of the pipe can be capped and a valve installed to prevent future treatment interruption while the pipe is connected to the future filter. Similarly, if new pumps are to be added, space for them should be provided and portions of the connecting pipes should be constructed.

The necessity for minimizing treatment interruptions during conversion must also be considered. Unless the entire secondary treatment facilities can be bypassed, as at Stockton, a portion of the original system will have to be functional during construction of the new facilities. This constraint may limit the amount of the existing facilities which can be reused.

Center Column and Distributor Support

A taller, heavier distributor is required to accommodate the greater height and heavier hydraulic loadings of the plastic media filters. A new center column is required to support the distributor, and a new foundation may be required to support the heavier structures. At Stockton, the original center column foundation was demolished and a larger foundation constructed.

The soil conditions beneath the filter floor should be investigated before excavation to determine what precautions will be needed to protect against a cave-in. Normally, sheet pilings will be needed. At Stockton, the soil was unusually stable, although shoring was used to comply with OSHA regulations.

A foul-air distribution chamber was incorporated in the foundation design at Stockton (Figure 11, Section 5) and at the Goleta, California, plant. Foul air from the headworks enters the chamber through a duct below the filter floor. Odorous gases are oxidized in passing through the filter.

Effluent Collection and Return

The effluent collection and return system collects the wastewater and sloughed biomass from the bottom of the filter. An efficient collection system performs its functions without allowing the solids to settle out or the wastewater to become septic and without providing a breeding place for the psycoda fly. Circular rock media filters have a sloping floor to direct effluent either to the center of the filter or to the outside edge of the filter. Generally, steeper slopes are provided for wastes with heavier suspended solids loadings. In converting a rock media filter, the existing filter floor would probably be reused so that a change in floor slope would be impractical.

In order to accommodate the increased loadings of the plastic media filters, the collection system may need to be enlarged. An external pipe collection system was added to the Stockton filters to supplement the existing collection channel. The additions were illustrated previously in Figure 16, Section 5. Effluent from the side of the filter opposite the return line flows in the original channel until it reaches the effluent collection boxes. The wastewater drops down into the boxes and flows through the new pipes into the return box. Effluent from the side of the filter near the return line flows entirely in the original channel. The collection channel in the Stockton filters was covered in the conversion in order to prevent the escape of air from the forced-air ventilation system.

A section view of a biofilter at the Simi Valley, California, Water Quality Control Plant is shown in Figure 50. The effluent collection channel in this design is within the filter walls; the media support system and the plastic media extend out over the channel. Although the Simi Valley design was for a new filter, it might be applicable in a filter conversion where a larger diameter filter is needed. If the existing rock media filter has an external collection channel, as at Stockton, the original wall could be demolished and a new wall constructed outside of the channel. The converted filter would then contain additional media volume over the collection channel.

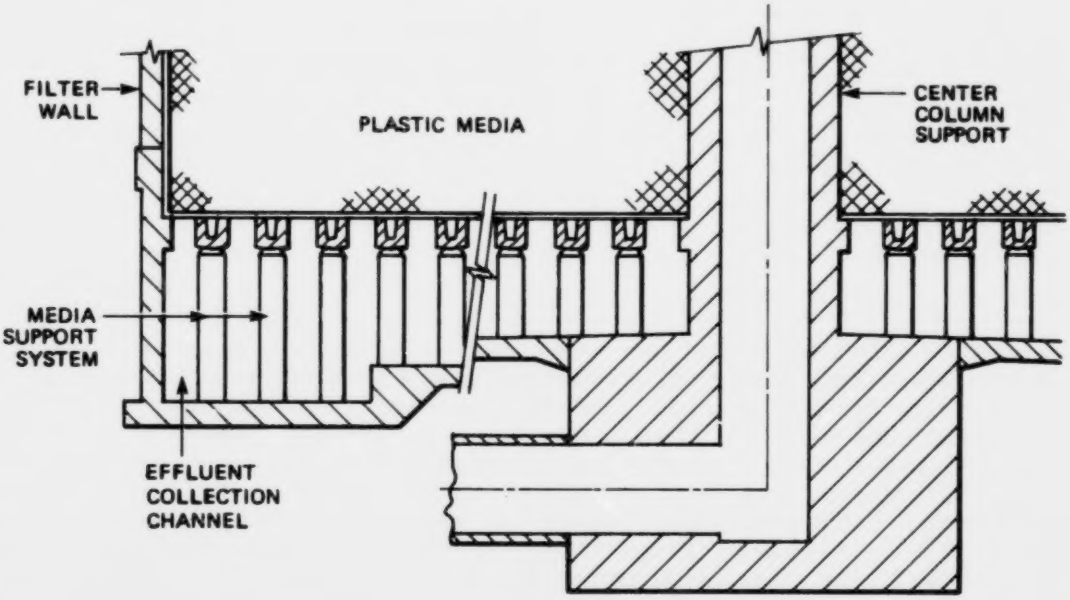


Figure 50. Biofilter cross section for Simi Valley, California, plant.

The effluent return lines to the distribution structure may also need to be enlarged since it is not desirable for them to operate under pressure. The pressure required to increase their capacity would have to come from wastewater backing up inside the filter collection channels.

Recirculation Structure and Pumping

The recirculation structure distributes the flow to the filters, controls the amount of filter effluent recirculation, and routes effluent to the secondary sedimentation tanks. Recycling of secondary effluent and sludge improves treatment efficiency. The amount of flow recycled increases with decreasing flows from the primary treatment processes to maintain a relatively high and uniform hydraulic application rate to the plastic media filters. The recycled secondary effluent and the primary effluent are mixed in the recirculation structure before being pumped to the filters.

The Stockton recirculation structure (Figure 19, Section 5) has a center chamber which receives primary effluent; an outer chamber receives filter effluent and supplies the secondary sedimentation tanks. Separate chambers are provided to prevent short-circuiting of primary effluent to the secondary sedimentation tanks. Secondary effluent is pumped into the center chamber to maintain a constant liquid level. Each filter is supplied by a variable-speed pump with manual controls.

The Lompoc, California recirculation structure uses a single chamber with weirs to direct the flows. A section view is shown in Figure 51. Primary effluent enters the chamber near the bottom where it mixes with the biofilter effluent in the main part of the structure. The biofilter supply pump intake is located on the opposite side of the structure separated from the inlets by baffles for mixing. Biofilter effluent enters a small compartment in the structure and overflows into the main chamber and into the chamber which supplies the secondary sedimentation tanks. Flow to the sedimentation tanks is by gravity. The magnitude of the biofilter effluent flow (approximately three times the average dry weather flow) assures that the flows will be in the directions shown and that short-circuiting of primary effluent to the secondary sedimentation tanks will not occur unless the biofilter supply pumps have shut down. The biofilter supply pumps are constant-speed types. A second pump is provided in case the first fails. Constant-speed pumps are used to ensure a constant feed rate to the filter. The recirculation ratio decreases with increasing plant flows.

Because the distribution structure is central to the secondary treatment process, upgrading an existing plant may require constructing an entirely new recirculation structure.

The capability of bypassing wastewater to the oxidation ponds at the Stockton plant made possible the modification of the existing recirculation structure. The original Lompoc biofilter and recirculation structure were not in service when plant modifications were begun. Thus, the existing recirculation structure could have been reused. Necessary modifications were so extensive, however, that it was easier to build an entirely new structure.

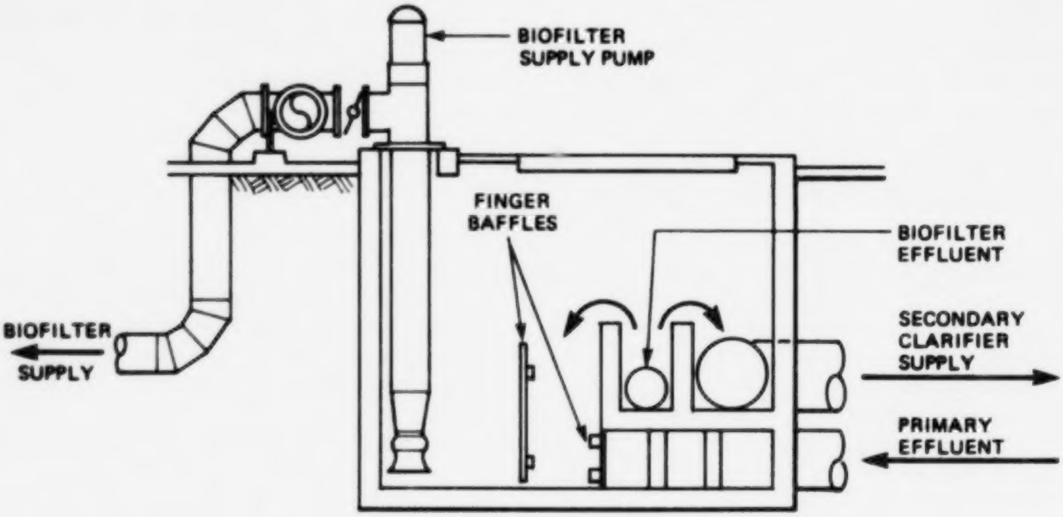


Figure 51. Recirculation structure for Lompoc, California, plant.

The recirculation structure should be designed to accommodate future expansions with a minimum of treatment interruption. The recirculation structure at Goleta was sized for peak wet weather flow (with no recycle) for an anticipated doubling of plant capacity.

Media Support System

The media support system physically supports the media and biomass, allowing solids and liquids to pass down and air to circulate freely through the filter. Early plastic media filters required intermediate support systems at several elevations in the tower. Plastic media is currently designed to be self-supporting to depths of 7.3 to 9.1 m (24 to 30 ft), with variations in wall thickness to accommodate varying weights to be supported. The wall thickness of the media blocks decreases from the bottom layer to the top layer of the filter.

The media support system should be designed for the particular type of media to be used. Media manufacturers usually recommend a support system which provides the best support for the media and which can be easily constructed. In preparing plans and specifications, the designer may want to provide alternative support system designs for each possible choice of media.

The media blocks are weakest near the edges; therefore, the support system should be designed to contact the media blocks at least 2.5 cm (1 in.) from the edge. The spacing of the support beams will be determined by the size of the media blocks. The media support system for the Stockton plant represented a compromise design to accommodate several different media types with different block sizes. This compromise resulted in a system which contacted the selected media at the edges. In order to maximize the contact area between the media and the support system, pier elevations were kept within close tolerances and support channels which were chipped or improperly formed were rejected.

The support system should be inexpensive to buy, inexpensive to construct, and corrosion resistant. Hydrogen sulfide may be present in the wastewater or may arise from improper operation of the filter. Concrete beams and piers are particularly suited for the support system. Concrete blocks are less satisfactory than solid concrete because they are porous and may support anaerobic growths. Redwood beams have been used in several filter designs. Redwood is satisfactory as long as it is wet; however, if the filter must be out of service for any length of time, the drying redwood may check. Aluminum gratings have also been used to support the media; these gratings tend to clog and may be quite expensive.

Plastic media filters require increased air circulation due to the larger media and biomass volumes and the increased loading rates. The old drain blocks should be discarded in favor of a taller support system. A minimum distance of 0.76 m (2.5 ft) between the floor and the support channels will provide room for maintenance. A commonly used system consists of solid walls running the length of the filter topped by beams at right angles to the walls as shown in Figure 52 (36). Solid walls will, however, decrease air circulation. Individual piers at spacings of several feet will provide a larger space for ventilation air (Figure 53) (36). The support system must also be designed to minimize the accumulation of biomass which hinders air and liquid flow and to prevent wastewater from collecting and causing corrosion.

The Stockton filter design contained isolated piers of concrete blocks supporting a precast concrete channel with large holes for increased air and liquid flow. Construction

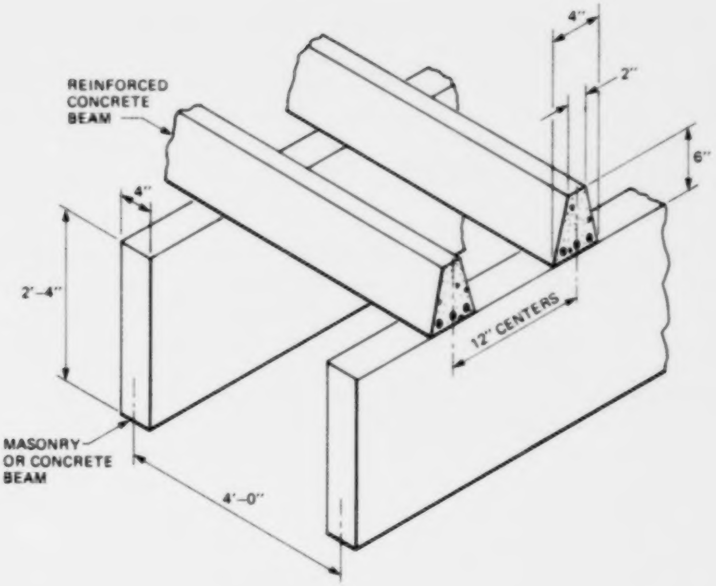


Figure 52. Media support system, with solid walls. (source: reference 36)

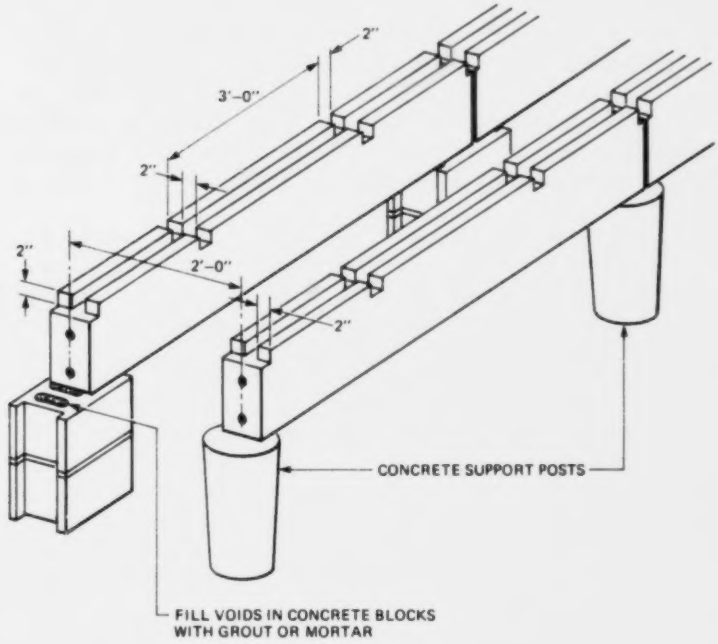


Figure 53. Media support systems using piers. (source: reference 36)

difficulties with the Stockton pier design resulted in an improved design for the Sunnyvale biofilters. The Stockton piers were constructed of concrete blocks; height adjustments had to be made by cutting blocks and varying the amount of mortar between the piers and the channels. To assure the proper elevations for the tops of the piers at Sunnyvale, despite variations in the filter floor elevations, the piers were poured in place to the desired elevation.

Ventilation System

Constant, even air flow is essential to maintain aerobic conditions; otherwise, the filters may produce objectionable odors. A tortuous path for air flow from the inlet to a portion of the media will cause that portion to be starved for air. The bottom or plenum chamber of the tower should be designed so that the pressure drop from the air inlet to any part of the bottom layer of media is very small compared to the pressure drop through the media. A relatively small pressure drop through the plenum chamber will insure an even air flow through the filter.

For colder climates, a method of restricting air flow may be desirable. Air flow is most easily restricted by doors or louvers at the entrance to the plenum chamber. Covering the filter will allow restriction of the flow at the air outlet.

In warmer, humid climates particularly, a forced-draft ventilation system may be necessary to insure continuous and adequate air flow, especially when organic loadings are high. The Stockton filter design included four large air ducts, each supplied by two rotary fans. The Lompoc design included a forced-draft ventilation system with round fiberglas air ducts rather than concrete ducts as in the Stockton design. Both of these systems use an upward air flow. A downdraft system could also be used with possibly better control of aerosols. Air containing odorous and corrosive substances would be exiting through the fans, however, producing a greater odor impact (because the fans are closer to the ground) and decreasing the operating life of the fans.

Overall Plant Configuration

The layout of the existing plant may greatly affect the feasibility of converting existing rock trickling filters to plastic media. Cost, flexibility and reliability in operation, and flexibility for future expansion and upgrading all need to be considered when evaluating conversion. For example, the cost of a long pipeline to connect the biofilters with another unit process may be greater than the cost savings resulting from use of the existing biofilter structure. As another example, it was pointed out previously that a new recirculation structure may need to be built if the old structure must be kept operating during construction. It may be difficult to construct a new one in a desirable location.

These are only two of the many problems which may result when attempts are made to utilize existing structures in such a conversion. They point out that early in the design phase, and even in the planning phase if possible, overall plant layout should be carefully inspected to determine whether conversion of existing rock media filters to plastic media is feasible and desirable.

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APPENDIX A

1969 DISCHARGE REQUIREMENTS
CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD
WASTE DISCHARGE REQUIREMENTS
FOR THE
CITY OF STOCKTON
MAIN WATER QUALITY CONTROL PLANT
SAN JOAQUIN COUNTY

Resolution No. 69-200 Adopted: 2/14/69

WHEREAS, the City of Stockton treats municipal and industrial wastes in a treatment works located on the San Joaquin River; and

WHEREAS, the nature of discharges from these facilities has been governed by Resolution No. 106 (51-85) adopted by the Central Valley Regional Water Quality Control Board on 7 November 1951; and

WHEREAS, treated wastes from the Stockton Main Plant are discharged to the San Joaquin River, or to Burns Cut-Off which is tributary to the San Joaquin River on either end; and

WHEREAS, the San Joaquin River and tributary channels in this area are a part of the Delta waters as defined in the "Water Quality Control Policy for the Sacramento-San Joaquin Delta" (Delta Water Quality Control Policy) as adopted by the State Water Quality Control Board (now State Water Resources Control Board); and

WHEREAS, beneficial uses of these waters, as identified in the aforesaid Policy are: domestic and municipal supply; agricultural and industrial supply; propagation, migration, sustenance, and harvest of fish, aquatic life and wildlife; recreation, esthetic enjoyment; navigation; and waste disposal, assimilation, and transport. In the Stockton area, recreation uses include boating, yachting, skiing, and swimming; and

WHEREAS, the aforementioned Policy prescribes a set of water quality objectives for these waters; and

WHEREAS, it is the intent of the Central Valley Regional Water Quality Control Board to preserve the quality of the

San Joaquin River and other Delta waters within the limits prescribed by the Delta Water Quality Control Policy; and

WHEREAS, it is further the intent of the Central Valley Regional Water Quality Control Board to so regulate waste discharges into these waters including the discharge from the City of Stockton Main Water Quality Control Plant so as to conform to the Delta Water Quality Control Policy; therefore be it

RESOLVED, that the following requirements shall govern the nature of any waste discharge from the Stockton Main Water Quality Control Plant:

1. Any of the plant effluent, reaching surface waters of the area, by any means whatsoever, shall:

    A. Be adequately disinfected and in no case shall cause the receiving waters to exceed a median fecal coliform level of 200/100 ml.

    B. Not cause the dissolved oxygen content of the receiving waters to fall below 5.0 mg/l at any time.

    C. Not cause the total nitrogen content of receiving waters to exceed 3.0 mg/l.

    D. Not cause concentrations of materials in the receiving waters which are deleterious to human, plant, or aquatic life.

    E. Not contain recognizable solids of sewage or waste origin.

    F. Not cause fungus growths in the receiving waters or on stream banks.

    G. Not cause objectionable concentrations of floating or emulsified grease or oil in Delta waters.

    H. Not cause detectable taste or odor in any public water supply.

    I. Not cause sludge deposits in the receiving waters.

    J. Not cause objectionable color in the receiving waters.

    K. Not cause the mean monthly Total Dissolved Solids (TDS) of receiving waters to increase above 500 mg/l, as measured on the basis of the average mean daily values for any calendar month.

L. Not cause the biocide content, as determined by the summation of individual concentrations, to increase above 0.6 ug/l; nor shall the concentrations of individual or combinations of pesticides in the Delta waters, as a result of this discharge, reach those levels found to be detrimental to fish or wildlife.

M. Not cause the pH of receiving waters to fall below 6.5, nor to exceed 8.5.

2. Neither the waste discharge nor the method of disposal shall cause a public nuisance by reason of odors or unsightliness.

3. Waste discharge shall not cause a pollution of usable ground or surface waters.

RESOLVED, further, that because of the time-lag inherent in public works construction, the City of Stockton is hereby directed to provide facilities on or before the dates shown on the attached "City of Stockton - Main Water Quality Control Plant - Modification and Expansion - Schedule of 23 November 1970"* to bring its waste dischage into full compliance with the requirements specified herein, except that the City of Stockton will be held fully accountable for complying with the requirements of Resolution No. 51-85 which shall also remain in effect to govern the waste discharges from the City of Stockton; and be it

RESOLVED, further, that the City of Stockton shall submit quarterly progress reports demonstrating that activities and construction for achieving compliance with these requirements is under way and on schedule; and be it

RESOLVED, further, that the discharger shall report promptly to the Central Valley Regional Water Quality Control Board any future changes in the discharge or changes in the conditions associated with its disposal; and be it

RESOLVED, further, that the discharger may be required to submit technical reports relative to the waste discharge as provided under Section 13055 of Division 7, California Water Code.

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*Amended by the California Regional Water Quality Control Board, Central Valley Region, on 23 November 1970.

If, in the future, there is a change in the conditions of the discharge, or use of the disposal area, it may be necessary for the Central Valley Regional Water Quality Control Board to revise these requirements.

These requirements do not constitute a license or permit; neither do they authorize the commission of any act resulting in injury to the property of another, nor do they protect the discharger from his liabilities under federal, state, or local laws.

/s/ John Van Assen
Chairman

ATTEST:

/s/ Charles T. Carnahan
Executive Officer

APPENDIX B

1974 DISCHARGE REQUIREMENTS
CENTRAL REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

ORDER NO. 74-453

NPDES NO. CA0079138

WASTE DISCHARGE REQUIREMENTS
FOR
CITY OF STOCKTON MAIN WATER QUALITY CONTROL PLANT
SAN JOAQUIN COUNTY

The California Regional Water Quality Control Board, Central Valley Region, (hereinafter Board), finds that:

1. The City of Stockton Main Water Quality Control Plant submitted a report of waste discharge NPDES No. CA0079138 dated 9 November 1973.

2. The City of Stockton Main Water Quality Control Plant discharges an average of 0.84 m^3/sec (19.2 mgd) and a maximum of 2.23 m^3/sec (51 mgd) of treated domestic and industrial waste from secondary treatment facilities into the San Joaquin River, a water of the United States, at a point 1.61 km(1 mi) downstream from the Highway 4 bridge, in the NW-1/4 of Section 17, T1N, R6E, MDB&M.

3. The report of waste discharge describes the existing discharge as follows:

   Average flow: 72,672 cubic meters per operating day (19.2 million gallons per operating day)
   Average temperature: 80F Summer; 54F Winter
   Average BOD_5: 14 mg/l
   Average total suspended solids: 35 mg/l
   Average settleable matter: 0.1 ml/l
   pH: 7.2 lowest monthly average; 8.8 highest monthly average

4. Maximum flows occur during the summer and fall months, with the major volume contributed by the

canneries connected to the city sewerage system. Liquid cannery wastes also provide the major organic loading to the plant during this period.

5. The City of Stockton proposes to consolidate wastewater treatment in the Stockton area by accepting all wastes presently going to the Stockton Northwest and Lincoln Village treatment plants. This consolidation will most likely occur within the next 5 yr.

6. The City of Stockton Main Water Quality Control Plant is presently in the middle of an expansion program which will result in continuing upgrading of plant effluent to meet more stringent requirements effective 1 July 1977. The plant capacity will be expanded to a maximum daily flow of 2.96 m^3/sec (67 mgd), a 7-day average maximum flow of 2.67M^3/sec (61 mgd), and a 30-day average maximum flow of 2.54 m^3/sec(58 mgd).

7. The Board on 15 June 1971 adopted an Interim Water Quality Control Plan for the Sacramento-San Joaquin Delta. The Interim Basin Plan contains water quality objectives for the San Joaquin River.

8. The beneficial uses of the San Joaquin River and Delta waters are: municipal, agricultural, and industrial supply; recreation; esthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources.

9. Effluent limitation and toxic and pretreatment effluent standards established pursuant to Sections 208b, 301, 302, 303(d), 304, and 307 of the Federal Water Pollution Control Act and amendments thereto are applicable to the discharge.

10. The discharge from the City of Stockton Main Water Quality Control Plant is presently governed by waste discharge requirements adopted by the Board on 7 November 1951 and 14 February 1969 in Resolution No. 51-85 and Resolution No. 69-200, respectively.

11. The Board has notified the discharger and interested agencies and persons of its intent to prescribe waste discharge requirements for this discharge and has provided them with an opportunity for a public hearing and an opportunity to submit their written views and recommendations.

12. The Board in a public meeting heard and considered all comments pertaining to the discharge.

13. This Order shall serve as a National Pollutant Discharge Elimination System permit pursuant to Section 402 of the Federal Water Pollution Control Act, or amendments thereto, and shall take effect 10 days from the date of hearing provided the Regional Administrator has no objections.

IT IS HEREBY ORDERED, the City of Stockton Main Water Quality Control Plant, in order to meet the provisions contained in Division 7 of the California Water Code and regulations adopted thereunder and the provisions of the Federal Water Pollution Control Act and regulations and guidelines adopted thereunder, shall comply with the following:

A. Effluent Limitations:

1. Prior to 1 July 1977, the discharge of an effluent in excess of the following limits is prohibited:

Constituent	Units	30-day Average	7-day Average	30-day Median	Daily Maximum
BOD(1)	mg/l	30	45	--	50
	lb/day	12,750	19,100	--	21,250
	kg/day	5,783	8,644	--	9,639
Settleable Matter	ml/l	--	--	--	0.1
Chlorine Residual	mg/l	--	--	--	0.1
Total Coliform(2) Organisms	MPN/100 ml	--	--	23	500
Grease and Oil	mg/l	10	--	--	15
	lb/day	4,255	--	--	6,380
	kg/day	1,930	--	--	2,894

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(1) 5-day, 20C Biochemical Oxygen Demand.

(2) Limits can be met at any point in the treatment system.

2. The arithmetic mean biochemical oxygen demand (5-day) and suspended solids in effluent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for influent samples collected at approximately the same times during the same period (85 percent removal).

3. The discharge shall not have a pH less than 6.5 nor greater than 8.5, nor shall it cause a change greater than 0.5 in the pH of the receiving waters.

4. Prior to 1 July 1977, the average daily dry weather discharge shall not exceed 193,035 cubic meters (51 million gallons).

5. Bypass or overflow of untreated or partially treated waste is prohibited.

6. The discharger shall use the best practicable cost effective control technique currently available to limit mineralization to no more than a reasonable increment.

7. Survival of test fishes in 96-hr bioassays of undiluted waste shall be no less than:

Minimum, any one bioassay.....	...70 percent
Median, any three or more consecutive bioassays........	..90 percent

8. The maximum temperature of the discharge shall not exceed the natural receiving water temperature by more than 20 Fahrenheit degrees.

9. The discharge shall not cause degradation of any water supply.

10. Effective 1 July 1977, the discharge of an effluent in excess of the following limits is prohibited:

Constituent	Units	30-day Average	7-day Average	30-day Median	Daily Maximum
BOD[1]	mg/l	10	20	--	30
	lb/day	4,835	10,175	--	16,765
	kg/day	2,193	4,615	—	7,605
Total Suspended Solids	mg/l	10	20	--	30
	lb/day	4,835	10,175	--	16,765
	kg/day	2,193	4,615	--	7,605
Settleable Matter	ml/l	—	—	--	0.1

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(1) 5-day, 20C Biochemical Oxygen Demand.

Constituent	Units	30-day Average	7-day Average	30-day Median	Daily Maximum
Chlorine Residual	mg/l	--	--	--	0.1
Total Coliform Organisms	MPN/100 ml	--	--	23	500
Grease and Oil	mg/l	10	--	--	15
	lb/day	4,835	--	--	8,380
	kg/day	2,193			3,801
Total Nitrogen(2)	mg/l	3.0	5.0	--	15.0
	lb/day	1,450	2,545	--	8,380
Flow	mgd m^3/sec	58	61	--	67

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(2) Compliance with these limitations shall apply from 15 July to 15 November.

B. Receiving Water Limitations:

1. Prior to 1 July 1977, the discharge shall not cause the dissolved oxygen concentration in the San Joaquin River to fall below 3.0 mg/l.

2. Effective 1 July 1977, the discharge shall not cause the dissolved oxygen concentration in the San Joaquin River to fall below the following levels:

Units	Minimum	Median	95th Percentile
mg/l	5.0	--	--
Percent of Saturation	--	85	75

When circumstances cause lesser levels upstream of the discharge, then the discharge shall cause no reduction. This requirement is subject to any modifications to the dissolved oxygen objectives as stated in the fully-developed Water Quality Control Plan for the Sacramento- San Joaquin Delta Basin, when the Plan becomes effective.

3. The discharge shall not cause visible oil, grease, scum, or foam in the receiving waters or watercourses.

4. The discharge shall not cause concentrations of any materials in the receiving waters which are deleterious to human, animal, aquatic, or plant life.

5. The discharge shall not cause esthetically undesirable discoloration of the receiving waters.

6. The discharge shall not cause fungus, slimes, or other objectionable growths in the receiving waters.

7. The discharge shall not cause bottom deposits in the receiving waters.

8. The discharge shall not cause floating or suspended materials of recognizable sewage origin in the receiving waters.

9. The discharge shall not increase the turbidity of the receiving waters by more than 10 percent over background levels.

10. The discharge either individually or in combination with other discharges shall not create a zone, defined by water temperatures of more than 1 Fahrenheit degree above natural receiving water temperature, which exceeds 25 percent of the cross-sectional area of the main river channel at any point.

11. The discharge shall not cause a surface water temperature rise greater than 4 Fahrenheit degrees above the natural temperature of the receiving waters at any time or place.

12. The discharge shall not cause the total nitrogen content of the receiving waters to exceed 3.0 mg/l.

13. The discharge shall not cause the mean monthly Total Dissolved Solids (TDS) in the receiving waters to exceed 500 mg/l.

14. The discharge shall not cause a violation of any applicable water quality standard for receiving waters adopted by the Board or the State Water Resources Control Board as required by the Federal Water Pollution Control Act and regulations adopted thereunder. If more stringent applicable water quality standards are approved

pursuant to Section 303 of the Federal Water Pollution Control Act, or amendments thereto, the Board will revise and modify this Order in accordance with such more stringent standards.

C. Provisions

1. Neither the discharge nor its treatment shall create a nuisance as defined in the California Water Code.

2. The City of Stockton Main Water Quality Control Plant shall comply with the following time schedule to assure compliance with Limitations A.2, A.10, B.2, and B.12 of this Order:

Task	Completion Date	Report of Compliance Due
Progress Report for Ongoing Project	10-1-74	10-15-74
Progress Report	4-1-75	4-15-75
Building Additions and Modifications	9-1-75	9-15-75
Preliminary Treatment Additions	11-1-75	11-15-75
Sludge Digestion Improvements	1-1-76	1-15-76
Progress Report	5-1-76	5-15-76
Solids Treatment and General Additions & Modifications	9-1-76	9-15-76
River Crossing	1-1-77	1-15-77
Advanced Wastewater Treatment Facilities	5-1-77	5-15-77
Full Compliance	7-1-77	7-15-77

The City of Stockton Main Water Quality Control Plant shall submit to the board on or before each compliance report date, a report detailing his compliance or noncompliance with the specific schedule date and task.

If noncompliance is being reported, the reasons for such noncompliance shall be stated, plus an estimate of the date when the discharger will be in compliance. The discharger shall notify the Board by letter when he has returned to compliance with the time schedule.

3. The City of Stockton Main Water Quality Control Plant shall comply with Limitation B.13 no later than 15 February 1979, and shall furnish the Board with quarterly progress reports beginning no later than 1 October 1974.

4. The requirements prescribed by this Order supersede the requirements prescribed by Resolution No. 51-85, adopted by the Board on 7 November 1951, which are hereby rescinded. The requirements prescribed by this Order amend the requirements prescribed by Resolution No. 69-200, adopted by the Board on 14 February 1969, which is hereby revised to include the time schedule in Provision C2 of this Order.

5. This Order includes items 1, 2, 4, and 5 of the attached "Reporting Requirements".

6. This Order includes items 1 through 11 inclusive of the attached "Standard Provisions".

7. This Order includes the attached "Industrial Wastewater Pretreatment Requirements".

8. The discharger shall comply with the Monitoring and Reporting Program No. 74-453 and the General Provisions for Monitoring and Reporting as specified by the Executive Officer.

9. This Order expires on 1 September 1979 and the City of Stockton Main Water Quality Control Plant must file a Report of Waste Discharge in accordance with Title 23, California Administrative Code, not later than 180 days in advance of such date as application for issuance of new waste discharge requirements.

10. In the event of any change in control or ownership of land or waste discharge facilities presently owned or controlled by the discharger, the discharger shall notify the succeeding owner or operator of the existence of this Order by letter, a copy of which shall be forwarded to this office.

11. The daily discharge rate is obtained from the following calculation for any calendar day:

$$\text{Daily discharge rate} = \frac{8.34}{N} \; {}_{1}^{N} \; Q_i \, C_i$$

in which N is the number of samples analyzed in any calendar day. Q_i and C_i are the flow rate (mgd) and the constituent concentration (mg/l) respectively, which are associated with each of the N grab samples which may be taken, in any calendar day. If a composite sample is taken, C_i is the concentration measured in the composite sample, and Q_i is the average flow rate occurring during the period over which samples are composited.

The 7-day and 30-day average discharge rates shall be the arithmetic average of all the values of the daily discharge rate calculated using the results of analyses of all samples collected during any 7 and 30 consecutive calendar day period, respectively. If fewer than four samples are collected and analyzed during any 30 consecutive calendar day period, compliance with the 30-day average discharge rate limitation shall not be determined. If fewer than three samples are collected and analyzed during any 7 consecutive calendar day period, compliance with the 7-day average rate limitation shall not be determined.

The daily maximum concentration shall be determined from the analytical results of any sample, whether discrete or composite.

I, JAMES A. ROBERTSON, Executive Officer, do hereby certify the foregoing is a full, true, and correct copy of an order adopted by the California Regional Water Quality Control Board, Central Valley Region, on 9/27/74.

JAMES A. ROBERTSON, Executive Officer

APPENDIX C

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

ORDER NO. 74-152

NPDES NO. CA0079138

WASTE DISCHARGE REQUIREMENTS FOR CITY OF STOCKTON MAIN WATER QUALITY CONTROL PLANT SAN JOAQUIN COUNTY

The California Regional Water Quality Control Board, Central Valley Region, (hereinafter Board), finds that:

1. The City of Stockton Main Water Quality Control Plant submitted a report of waste discharge NPDES No. CA0079138 dated 9 November 1973.

2. The City of Stockton Main Water Quality Control Plant discharges an average of 0.84 m^3/sec (19.2 mgd) and a maximum of 2.23 m^3/sec (51 mgd) of treated domestic and industrial waste from secondary treatment facilities into the San Joaquin River, a water of the United States, at a point one mile (1 mi) downstream from the Highway 4 bridge, in the NW-1/4 of Section 17, T1N, R6E, MDB&M.]

3. The report of waste discharge describes the existing discharge as follows:

   Average flow: 72,672 cubic meters per operating day (19.2 million gallons per operating day)
   Average temperature: 80F Summer; 54F Winter
   Average BOD_5: 14 mg/l
   Average total suspended solids: 35 mg/l
   Average settleable matter: 0.1 ml/l
   pH: 7.2 lowest monthly average; 8.8 highest monthly average

4. Maximum waste flows occur during the summer and fall months, with the major volume contributed by the

canneries connected to the city sewerage system. Liquid cannery wastes also provide the major organic loading to the plant during this period.

5. The City of Stockton has consolidated wastewater treatment in the Stockton area by accepting all wastes from the Stockton Northwest, Stockton Airport, and Lincoln Village treatment plants.

6. The City of Stockton Main Water Quality Control Plant has completed an expansion program, including tertiary facilities, which will result in upgrading of plant effluent to meet more stringent requirements. The plant capacity will be expanded to a maximum daily flow of 67 mgd, a 7-day average maximum flow of 61 mgd, and a 30-day average maximum flow of 58 mgd.

7. The Board on 25 July 1975 adopted a Water Quality Control Plan for the Sacramento-San Joaquin Delta. The Basin Plan contains water quality objectives for the San Joaquin River and Delta waters.

8. The beneficial uses of the San Joaquin River and Delta waters are municipal, agricultural, and industrial supply; recreation; esthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources.

9. Effluent limitations and toxic and pretreatment effluent standards established pursuant to Sections 208b, 301, 302, 304, and 307 of the Federal Water Pollution Control Act and amendments thereto are applicable to the discharge.

10. The discharge from the City of Stockton Main Water Quality Control Plant is presently governed by waste discharge requirements adopted by the Board on 28 July 1978 in Order No. 78-105.

11. The Board has notified the discharger and interested agencies and persons of its intent to prescribe waste discharge requirements for this discharge and has provided them with an opportunity for a public hearing and an opportunity to submit their written views and recommendations.

12. The Board in a public meeting heard and considered all comments pertaining to the discharge.

13. The action to adopt an NPDES permit is exempt from the provisions of the California Environmental Quality Act in accordance with Section 13389 of the Water Code.

14. This Order shall serve as a National Pollutant Discharge Elimination System permit pursuant to Section 402 of the Federal Water Pollution Control Act, or amendments thereto, and shall take effect 10 days from the data of hearing provided the Regional Administrator, EPA, has no objections.

IT IS HEREBY ORDERED, the City of Stockton Main Water Quality Control Plant, in order to meet the provisions contained in Division 7 of the California Water Code and regulations adopted thereunder and the provisions of the Federal Water Pollution Control Act and regulations and guidelines adopted thereunder, shall comply with the following:

A. Effluent Limitations:

1. The discharge of an effluent in excess of the following limits is prohibited from 1 November through 31 July:

Constituent	Units	30-day Average	7-day Average	30-day Median	Daily Maximum
a. BOD[1]	mg/l	30	45	--	50
	lb/day	12,750	19,100	--	21,250
	kg/day	5,800	8,700	--	9,600
b. Total Suspended Solids	mg/l	30	45	--	50
	lb/day	12,750	19,100	--	21,250
	kg/day	5,800	8,700	--	9,600
c. Settleable Matter	ml/l	--	--	--	0.1
d. Chlorine Residual	mg/l	--	--	--	.02
e. Total Coliform[2] Organisms	MPN/100 ml	--	--	23	500
f Grease and Oil	mg/l	10	--	--	15
	lb/day	4,835	--	--	8,380
	kg/day	2,200	--	--	3,800
g. Flow	mgd	58	61	--	67

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(1) 5-day, 20C Biochemical Oxygen Demand.

(2) Limits can be at any point in the treatment system.

2. During the period 1 August through 31 October the discharge of an effluent in excess of the limits contained in A.1. above is prohibited excepting:

Constituent	Units	30-day Average	7-day Average	30-day Median
a. BOD	mg/l	10	20	30
	lb/day	4,840	10,180	16,770
	kg/day	2,200	4,600	7,600
b. Total Suspended Matter	mg/l	10	20	30
	lb/day	4,840	10,180	16,770
	kg/day	2,200	4,600	7,600

3. The arithmetic mean biochemical oxygen demand (5-day) and suspended solids in efflent samples collected in a period of 30 consecutive days shall not exceed 15 percent of the arithmetic mean of the values for influent samples collected at approximately the same times during the same period (85 percent removal).

4. The discharge shall not have a pH less that 6.0 nor greater than 8.5, nor shall it cause a change greater than 0.5 in the pH of the receiving waters.

5. Bypass or overflow of untreated or partially treated wastes is prohibited.

6. The discharger shall use the best practicable cost effective control technique currently available to limit mineralization to no more than a reasonable increment.

7. Survival of test fishes in 96-hour bioassays of undiluted waste shall be no less than:

   Minimum, any one bioassay 70%

   Median, any three or more consecutive bioassays 90%

8. The maximum temperature of the discharge shall not exceed the natural receiving water temperature by more than 20 Fahrenheit degrees.

9. The discharger shall not cause degradation of any water supply.

B. Receiving Water Limitiations:

1. The discharge shall not cause the dissolved oxygen concentration in the San Joaquin River to fall below the following levels:

Units	Minimum	Median	95 Percentile
mg/l	5.0	--	--
Percent of Saturation	--	85	75

2. When circumstances cause dissolved oxygen levels less than 5.0 mg/l downstream or upstream of the discharge, then the City of Stockton facility shall be operated to comply as stipulated in A.2.

3. The discharge shall not cause visible oil, grease, scum, or foam in the receiving waters or watercourses.

4. The discharger shall not cause concentrations of any materials in the receiving waters which are deleterious to human, animal, aquatic, or plant life.

5. The discharger shall not cause esthetically undesirable discoloration of the receiving waters.

6. The discharger shall not cause fungus, slimes, or other objectionable growths in the receiving waters.

7. The discharge shall not cause bottom deposits in the receiving waters.

8. The discharge shall not cause floating or suspended materials of recognizable sewage origin in the receiving waters.

9. The discharge shall not increase the turbidity of the receiving waters by more than 10% over background levels.

10. The discharger either individually or in combination with other discharges shall not create a zone, defined by water temperatures of more than one Fahrenheit degree above natural

receiving water temperature, which exceeds 25 percent of the cross-sectional area of the main river channel at any time or place.

11. The discharge shall not cause a surface water temperature rise greater than 4 Fahrenheit degrees above the natural temperature of the receiving waters at any point.

12. The discharge shall not cause a violation of any applicable water quality standard for receiving waters adopted by the Board or the State Water Resources Control Board as required by the Federal Water Pollution Control Act and regulations adopted thereunder. If more stringent applicable water quality standards are approved pursuant to Section 303 of the Federal Water Pollution Control Act, or amendments thereto, the Board will revise and modify this Order in accordance with such more stringent standards.

C. Provisions

1. Neither the discharge not its treatment shall create a nuisance as defined in the California Water Code.

2. If future studies indicate that additional nitrogen removal is necessary to protect water quality, the Board may revise and modify this order to include more stringent nitrogen limitations.

3. The City of Stockton Main Water Quality Control Plant shall diligently pursue and enforce source control of Total Dissolved Solids (TDS) to minimize the level of TDS discharged and shall furnish a report no later than 15 February of each year describing the major sources of TDS and control measures which were taken during the previous year.

4. The requirements prescribed by this Order supercede the requirements prescribed by Order No. 78-105 which is hereby rescinded.

5. This Order includes the attached "Standard Provisions and Reporting Requirements" for Municipal Discharges.

6. This Order includes the attached "Industrial Wastewater Pretreatment Requirements."

7. This discharger shall comply with the Monitoring and Reporting Program No. 79-152 and the General provisions for Monitoring and Reporting as specified by the Executive Officer.

8. This order expires on 1 April 1980 and the City of Stockton Main Water Quality Control Plant must file a Report of Waste Discharge in accordance with Title 23, California Administrative Code, not later than 180 days in advance of such date as application for issuance of new waste discharge requirements.

9. In the event of any change in control or ownership of land or waste discharge facilities presently owned or controlled by the discharger, the discharger shall notify the succeeding owner or operator of the existence of this order by letter, a copy of which shall be forwarded to this office.

10. The daily discharge rate is obtained from the following calculation for any calendar day:

$$\text{Daily discharge rate} = \frac{8.34}{N}\sum_{1}^{N} Q_i\ C_i$$

in which N is the number of samples analyzed in any calendar day. Q_i and C_i are the flow rate (MGD) and the constituent concentration (mg/l), respectively, which are associated with each of the N grab samples which may be taken in any calendar day. If a composite sample is taken, C_i is the concentration measured in the composite sample, and Q_i is the average flow rate occurring during the period over which samples are composited.

The 7-day and 30-day average discharge rates shall be the arithmetic average of all the values of daily discharge rate calculated using the results of analyses of all samples collected during any 7 and 30 consecutive calendar day period, respectively. If fewer than four samples are collected and analyzed during any 30 consecutive calendar day period, compliance with the 30-day average discharge rate limitation shall not be determined. If fewer than three samples are collected and analyzed during any

7 consecutive calendar day period, compliance with the 7-day average rate limitation shall not be determined.

The daily maximum concentration shall be determined from the analytical results of any sample whether discrete or composite.

I, JAMES A. ROBERTSON, Executive Officer, do hereby certify the foregoing is a full, true, and correct copy of an order adopted by the California Regional Water Quality Control Board, Central Valley Region, on June 22, 1979.

JAMES A. ROBERTSON, Executive Officer

APPENDIX D

DESCRIPTION OF SAMPLING PROGRAM

In order to determine the performance characteristics for the plastic media trickling filters constructed at Stockton, a special 1-yr sampling program was undertaken. Because the three rock media and the three plastic media filters operated in parallel from the common recirculation sump serving all the trickling filters, it was impossible to measure the performance of the plastic units independently of the rock filters. The city agreed, therefore, to shut down the three rock media filters during the sampling program. Loadings on the filters during this time were sufficiently below the design loadings to allow this operating change to be implemented without an adverse effect on performance. The sampling program was begun on March 15, 1976, and completed on March 16, 1977. Results of the sampling program are presented in Section 7 and in Appendix E. Discussed below are sampling and analytical techniques, sampler operation and performance, and the history of the sampling program, including problems, special tests, and a description of plant operation during the sampling program.

SAMPLING AND ANALYTICAL TECHNIQUES

The analyses conducted for the sampling program are shown in Table 12, Section 7. They include total and soluble BOD_5, total and volatile suspended solids, alkalinity, total and soluble COD, nitrogen forms, and total phosphorus. Plant records were used to obtain data on flow, pH, dissolved oxygen, and wastewater temperature. Flow was measured by Parshall flumes in the plant headworks. Grab samples taken at approximately 1:00 p.m. each day were used to determine the other three parameters. Except for total and soluble BOD_5 and primary effluent alkalinity, which were measured once per week, analyses were performed three times per week. BOD_5, total and volatile suspended solids, and alkalinity analyses were performed at Brown and Caldwell's Environmental Sciences Division in San Francisco. The remaining analyses were performed at the Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

Total COD, TKN, and total phosphorus samples were preserved with sulfuric acid to a pH of 2 or less. Ammonia, nitrate, and nitrate nitrogen samples were preserved with 5 ml of chloroform per 250 ml of sample. Soluble COD samples were filtered through a millipore membrane filter and preserved with sulfuric acid to a pH of 2 or less. Three 24-hr composite samples of each of the above-preserved types were collected each week and shipped to Cincinnati the following Monday morning by air freight.

COD analyses were conducted in accordance with Standard Methods (36). TKN samples were analyzed using semi-macro (100-ml flasks) Kjeldahl digestion followed by distillation and analysis of the free ammonia nitrogen produced via the automated colorimetric phenate method (37). Nitrite and nitrate nitrogen were determined simultaneously by stoichiometric reduction of nitrate ion to nitrite ion with hydrazine sulfate and measurement of the resultant nitrite by standard automated colorimetric procedures (38). Nitrite nitrogen was then analyzed separately without the hydrazine sulfate reduction step and nitrate nitrogen calculated by subtraction. Total phosphorus analyses were performed using the automated colorimetric ascorbic acid reduction method (37).

For total and soluble secondary effluent BOD_5, it was believed that nitrification in the BOD bottle might cause values to be erroneously high. Therefore, suppression of nitrification was undertaken initially with 0.1 ammonia nitrogen, which in such high concentrations is toxic to nitrifying organisms, and later with allylthiourea (ATU).

On May 3, 1976, parallel tests were begun which ran for 4 wk. In these tests, BOD_5 analyses were performed with ATU and ammonia nitrogen used for nitrification suppression. A parallel, control test was run without nitrification suppression. Results of the tests, discussed in greater detail below under sampling program history, indicated that ammonia nitrogen inhibited carbonaceous oxidation as well as nitrification. Therefore, for the remainder of the study, ATU was used to suppress nitrification in the BOD bottle.

In Section 7 and in Appendix D, secondary effluent total and soluble BOD_5 concentrations for the first 8 weeks of the study have been adjusted upward using the results of the parallel test involving ammonia nitrogen and ATU.

SAMPLER OPERATIONS

Sampling for the special program was accomplished using four portable, refrigerated composites samplers manufactured by Instrumentation Specialties Company (ISCO). These samplers, shown in Figure D-1, are capable of receiving a flow-proportional signal from a flow meter or other device. Because of the location of the samplers, far from the existing plant flowmeter, it was decided to attempt to simulate the diurnal flow variations through the use of a timer manufactured by the Tork Company. The timers allowed a contact closure signal to be sent to the samplers at intervals as frequent as every 5 min.

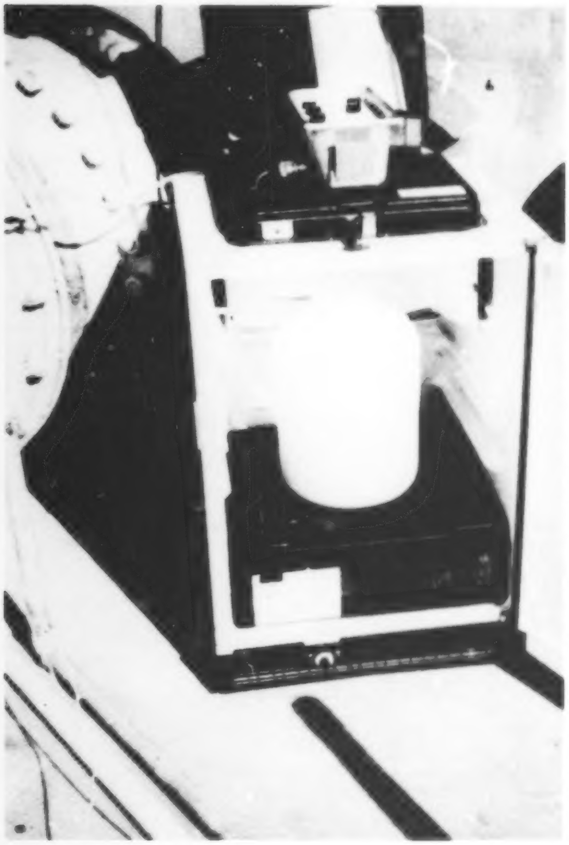

Figure D-1. Isco Model 1580R sampler. Twenty-four-hr flow, proportional composite samples were taken 3 days per week at four sampling locations.

Figure D-2 illustrates the diurnal typical flow variation curve at the Stockton plant for the noncanning season. The curve represents hourly flow values averaged over a 7-day period. Also shown in the figure is the simulated flow pattern developed using the Tork timers. This technique proved to be very effective in simulating flow fluctuations at the Stockton plant. This method was much more economical than attempting to use the actual measured flows to trigger the samplers. As the diurnal flow variation for the canning season is significantly different from that shown in Figure D-2, a different simulated flow pattern was developed for that period of the study.

The primary influent sampler was located at the distribution structure for primary clarifiers No. 1 through 4. This location had two disadvantages. First, it was downstream from the grit removal channels, and second, it was downstream from the point at which secondary sludge was returned to the headworks to be removed in the primary clarifiers and delivered to the digesters. It would have been more desirable to have located the sampler upstream from these points, but the enclosed headworks required explosion-proof equipment which was not available.

The primary effluent sampler was located at the top of the trickling filter circulation sump. Because the water in the circulation structure consists of both primary effluent and unsettled trickling filter effluent, it was necessary to locate the end of the sampler suction tube within the 1.5-m (60-in.) primary effluent line connecting the primary clarifiers to the distribution structure. The device used to hold the end of the sampling tube in place is shown in Figure D-3. Installation of the sampling line is shown in Figure D-4. This was the only point at which a representative primary effluent sample could be obtained.

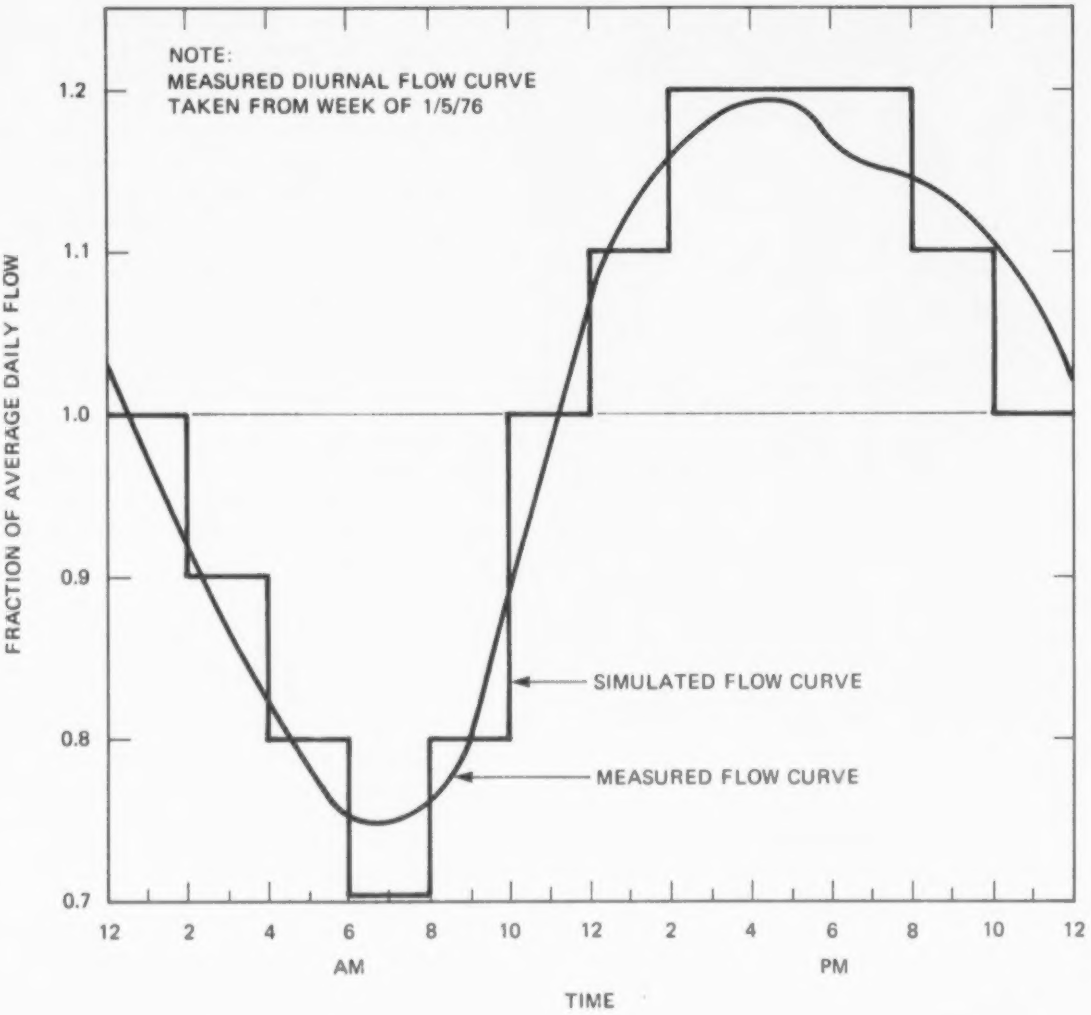

Figure D-2. Measured and simulated diurnal flow variation curves.

The unsettled trickling filter effluent sampler was located at the outer box of the filter circulation sump. Its proximity to the primary effluent sampler allowed a single timer to be used for both.

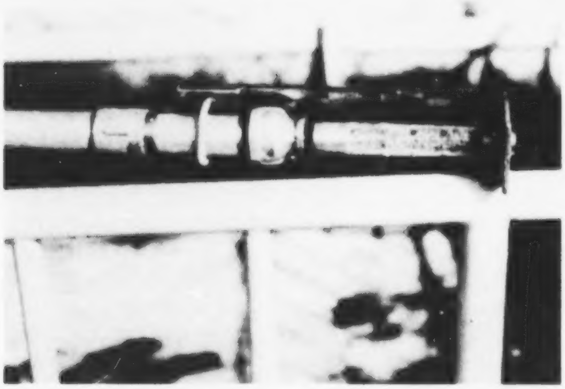

Figure D-3. Sampling tube strainer held in place by clamp.

Figure D-4. Installation of primary effluent sampling line. To obtain a representative sample, the sampling tube had to be located in the end of the primary effluent line approximately 4.6 m (15 ft) below the water surface in the recirculation structure.

The secondary effluent sampler was located on the levee between the secondary clarifiers and the river crossing. This location was necessary in order to obtain a representative sample from all the secondary clarifiers. This was considered necessary because of the flow distribution problems among the secondary clarifiers. As chlorination of secondary clarifier influent was practiced for disinfection purposes, sodium thiosulfite was added to the collection bottle in the secondary effluent sampler to eliminate any effect of the chlorine on the measured parameters.

The Isco Model 1580R sampler is a compositing sampler which can be operated either at a specified time interval or as a flow-proportional sampler if a contact closure is provided. The refrigerator temperature can be adjusted from 0 to 8 C with a calibrated control. Suction lines for the sampler are 0.64 cm (1/4-in.) in diameter, and a 0.64-cm (1/4-in.) strainer is provided at the end of the suction tube. A sample volume of up to 18.9 l (5 gal) can be taken. An automatic shutoff device prevents the sample bottle from overflowing.

Operational reliability of the samplers was a serious problem throughout the project. Initially, the tubing inside the peristaltic pump unit deteriorated rapidly. Eventually this was solved by allowing the length of tubing within the pump unit to reach "natural" length before being clamped at both ends. A more serious problem, which required a shipment of several samplers back to the manufacturer for repairs, resulted from an insufficient volume of wastewater being pumped at each sampling. This apparently resulted from the malfunction of a counter within the pump unit, which registered the number of turns of the pump required for a specified sample volume. Toward the end of the study, a third problem developed. This involved deterioration of the gears within the pump, which also required return of the units to the manufacturer.

During a significant portion of the study, three or fewer samplers were being operated at any given time. During periods of sampler breakdown, sampler mechanisms were switched, if necessary, to ensure that primary effluent and secondary effluent was being sampled with the automatic samplers. Those points in the waste stream not sampled automatically were hand sampled by the plant staff and composited over a 24-hr period. These samples were not flow-proportioned, however.

SAMPLING PROGRAM HISTORY

Any long-term sampling program undertaken at an operating wastewater treatment plant will necessarily encounter operational changes over the course of the program. Principal operational changes normally undertaken at Stockton include the use of fewer primary and secondary clarifiers during the noncanning season when the hydraulic loading is much lower. Further, certain plant components may be out of service for a time. During the first 9 wk of the Stockton sampling program, only two of the three plastic media towers were operating. The third tower was shut down to allow experiments with insertion of a plastic liner between the media and the tower wall to eliminate the leakage problem described in Section 6. Shown in Figure 32 in Section 7 is an operational history for the Stockton plant during the sampling program. Indicated in the figure is the operation of the towers, primary and secondary clarifiers, and forced-draft ventilation fans.

During the course of the program, several auxiliary tests were undertaken in order to develop specific information. One test mentioned previously was the comparison of ammonia nitrogen and ATU for nitrification suppression in the BOD test.

Shown in Table D-1 are the results of parallel tests taken over a 3-wk period. In the first column are secondary effluent BOD_5 concentrations measured by the Stockton plant laboratory staff without nitrification suppression. In the second two columns are secondary effluent BOD_5 concentrations measured by Brown and Caldwell using ammonia nitrogen and ATU, respectively, for nitrification suppression. The average BOD_5 concentrations over the 3-wk period were approximately equal for the samples suppressed with ATU and for the samples for which nitrification was not suppressed. Those samples to which ammonia nitrogen was added had an average BOD_5 concentration of approximately 15 mg/l as compared with 23 mg/l for those suppressed with ATU and those to which no suppnessant was added. Conclusions resulting from these tests are that either ammonia nitrogen suppresses both carbonaceous BOD and nitrification or that ATU is ineffective in inhibiting nitrification. Most previous information supports the first conclusion, however, that ammonia nitrogen, when used to suppress nitrification, can also suppress carbonaceous BOD.

TABLE D-1. PARALLEL TESTS ON NITRIFICATION SUPPRESSION

Date	Measured BOD_5 concentration, mg/l[a]		
	No inhibitor[b]	Ammonium chloride[c]	ATU[c]
5/10/76	-	8	-
5/11/76	22	12	29
5/12/76	27	16	-
5/17/76	-	17	29
5/18/76	-	22	33
5/19/76	27	33	-
5/24/76	22	12	12
5/25/76	17	8	19
5/26/76	20	11	14
Average	23	15	23

[a] Tests conducted on secondary effluent.

[b] Analyzed by Stockton plant staff.

[c] Analyzed by Brown and Caldwell.

These tests indicated that nitrification within the BOD bottle was not a significant problem during the sampling program at Stockton. Nonetheless, ATU was used for nitrification suppression during the remainder of the program.

Similar tests undertaken at Seattle, Washington, also indicate that ATU is an effective inhibitor of nitrification in the BOD test and that ammonia nitrogen inhibits carbonaceous BOD as well as nitrification. Results of one of the tests carried out at Seattle are shown in Table D-2. Four sets of ammonia-free solutions of glucose and glutamic acid were set up using diluted water seeded with settled primary effluent. Ten replicate samples were prepared for each set. The analysis compared results using no inhibitor, ammonium chloride, and ATU. In this test, any differences occurring could only be due to inhibition of carbonaceous oxidation by the nitrification suppressants. While the samples with no inhibitor and with ATU added gave approximately equal BOD_5 values, the samples with ammonium chloride added had significantly lower BOD_5 values. This again indicates that ATU is a more reliable inhibitor of nitrification and does not inhibit carbonaceous BOD.

TABLE D-2. NITRIFICATION SUPPRESSION TESTS CONDUCTED FOR SEATTLE PILOT PLANT

Test number	Measured BOD_5 concentration, mg/l[a]		
	No inhibitor	Ammonium chloride	ATU
1	246	180[b]	240
2	252	234	252
3	246	222	252
4	240	228	246
5	256	234	252
6	246	216	234[b]
7	246	204	246
8	234	216	258
9	228	204	252
10	252	222	252
Average	245	220	250

[a] Tests conducted on ammonia-free, glucose, glutamic acid solutions.

[b] Not included in average.

As a result of the parallel tests conducted at Stockton and discussed above, all secondary effluent BOD_5 concentrations measured prior to May 10 have been increased by 50 percent to account for the addition of ammonia nitrogen during this earlier period.

Another special test undertaken during the sampling program involved the measurement of heavy metals concentrations in the sludge sloughed from the trickling filters. Poor nitrification performance during the first part of the study led to the suspicion that high heavy metals concentrations in the slime developed on the trickling filter could be toxic to the nitrifying organisms. On May 17, 1976, a sample of sludge was collected from the secondary clarifier underflow, refrigerated, and delivered to EPA, San Francisco. Analyses were performed for zinc, mercury, chromium, nickel, arsenic, and copper. Results are summarized in Table D-3, along with values obtained in tests performed elsewhere. The table shows that the values obtained at Stockton are not unusually high and, therefore were probably not the cause of poor nitrification performance.

Later in the program, two operational changes were instituted in an attempt to improve performance. The first involved increasing total hydraulic loading (raw plus recycle) on the towers, and the second involved increasing the air flow through the forced draft ventilation system to ensure an adequate oxygen supply for the nitrifying organisms in the tower.

Because the Stockton towers are designed for a very low organic loading during the noncanning season to achieve nitrification, the total hydraulic loading on the tower is also quite low. Although the total flow is not measured at Stockton, hydraulic analysis of the supply pumps and piping indicated that the total loading being obtained was approximately 0.024 $m^3/min/m^2$ (0.6 gpm/ft^2) which is lower than the 0.031 to 0.041 $m^3/min/m^2$ (0.75 to 1.0 gpm/ft^2) normally recommended as the minimum loading to ensure wetting of the entire media surface. Therefore, it was requested that the city, starting in mid-October 1976, increase the hydraulic loading to the towers by increasing the speed of the variable speed supply pumps.

TABLE D-3. HEAVY METALS CONCENTRATIONS IN SLUDGE

Constituent	Concentration mg/kg dry solids		
	Stockton[a]	Seattle[b]	Typical range[c]
Zinc	2,600	2,560	1,000 - 3,000
Mercury	3	4.5	3 - 7
Chromium	600	570	100 - 1,000
Nickel	42	110	50 - 500
Copper	750	830	400 - 2,000

[a] Trickling filter solids.

[b] Digested primary sludge.

[c] Source: Environmental Science and Technology, 10, 683 (July 1976). Measured on various types of sludges.

Another operational change made at this time was to increase the number of forced draft ventilation fans operating at the towers. Although measurements undertaken with two or fewer (out of eight) fans operating indicated that dissolved oxygen levels in the tower influent were sufficiently high to ensure nitrification, it was believed that these values may have been erroneously high due to dissolved oxygen being added to the wastewater as it dropped from the bottom of the media to the floor of the tower. Thus, it was requested that the city increase the number of fans operating to at least four of eight at each tower.

Data taken before and after the changes in operating procedure exhibit improved performance after the changes were made. A more complete discussion of these differences is presented in Section 7.

Later in the study, another change was made in the operation of the forced draft ventilation fans. Observation of the secondary clarifiers during the middle of the day showed an increase in turbidity and apparent short-circuiting of influent which rose to the surface near the feedwell and moved rapidly across the clarifier to the effluent troughs. This phenomonen had been observed for some time by the plant staff, but no explanation has been found for its occurrence. After observing the phenomonen for several months during the sampling program, it was hypothesized that the short circuiting may have been due to temperature/density gradients set up within the clarifier. It was theorized that with low hydraulic loadings and high air flows to employed promote nitrification in the towers, that colder air temperatures and lower flows at night resulted in a greater cooling of the wastewater as it passed through the towers. As the wastewater flow and temperature increased in the morning hours, the drop in wastewater temperature through the towers would decrease and the water entering the clarifiers would be warmer and lighter. If the difference in density were sufficiently great, short-circuiting of the type observed might be expected to occur.

As discussed in Section 7, water temperature profiles were measured and temperature gradients were found although no correlation with the occurrence of short-circuiting could be detected. It is still uncertain whether a causal relation exists between temperature variations and short-circuiting.

Other plant operational changes, which were incidental to the sampling program, also occurred during the 1-yr period. From the beginning of the sampling program until May 12, 1976, only two of the three plastic media towers were being operated. The third tower was shut down during this period to allow experimentation with insertion of a plastic liner between the media and the tower wall in order to prevent the leakage which was occurring through the wall. This change did not have an adverse effect on the sampling program. In fact, the increased organic loading through the towers during this period approximated the design loading and, therefore, allowed a valuable comparison between design and performance.

The other significant event during the sampling program involved the inability of the primary clarifier solids handling mechanism to remove large quantities of solids received during the canning season. Normal procedure at Stockton is for the secondary sludge to be returned to the headworks. Combined primary and secondary sludges are then removed from the primary sedimentation tanks and pumped to the digesters. During the peak of the canning season, the solids loadings on the primaries were sufficiently high that solids carryover to the secondary treatment portion of the plant was occurring. When these solids entered the secondary clarifiers, they settled out and were returned to the plant headworks. Thus, a build-up of solids was occurring within the primary and secondary treatment portions of the plant. To solve this problem, the plant staff constructed a temporary sludge conveyance line from the secondary sludge collection box directly to the sludge lagoons.

Secondary sludge was then pumped to the lagoons at a rate sufficiently high to eliminate the build-up which had occurred. In a short period of time, the plant influent solids load decreased and the temporary conveyance line was no longer needed. Operation of the temporary line began on August 21, 1976. All of the secondary sludge was transferred directly to the lagoons for the next several weeks of the canning season.

APPENDIX E

DAILY DATA FROM SAMPLING PROGRAM

TABLE E-1. DAILY VALUES FOR FLOW, BOD_5, SOLUBLE BOD_5, AND SOLUBLE COD

Date	Flow, mgd[a]		BOD_5, mg/l			Soluble BOD_5, mg/l		COD, mg/l				Soluble COD, mg/l	
	Infl.	Recyc.	Raw Infl.	Prim. Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.
3/15/76	16[b]	20	270	180	-	86	-	750	380	210	100	200	57
3/16/76	16	21	300	180	-	-	-	700	430	230	130	180	83
3/17/76	16	20	300	150	8	-	-	680	330	200	120	150	74
3/22/76	16	24	300	160	34	-	-	650	440	220	120	75	85
3/23/76	16	24	340	240	15	96	8	720	360	170	120	86	84
3/24/76	16	19	-	200	23	-	-	-	330	180	120	83	77
3/29/76	16	21	250	140	29	-	-	560	390	290	110	91	94
3/30/76	16	20	260	150	29	-	-	520	410	260	110	100	77
3/31/76	16	21	300	160	57	43	29	610	340	260	120	130	77
4/5/76	16	21	270	200	13	58	5	530	340	240	120	100	84
4/6/76	16	21	300	200	54	-	-	590	450	240	130	120	97
4/7/76	16	17	260	150	-	-	-	550	350	260	-	79	-
4/12/76	16	19	210	130	12	-	-	490	270	210	97	82	69
4/13/76	16	19	250	140	10	44	4	510	370	200	110	81	78
4/14/76	16	19	260	140	9	-	-	740	530	370	110	82	75
4/19/76	16	15	250	140	6	-	-	670	310	250	100	88	73
4/20/76	16	16	220	140	3	-	-	490	330	170	95	82	71
4/21/76	16	20	220	140	29	55	8	550	370	180	100	78	68
4/26/76	16	20	220	140	13	52	9	740	330	190	130	160	100
4/27/76	16	19	230	130	8	-	-	510	290	180	140	130	100
4/28/76	16	20	300	170	-	-	-	690	430	200	150	150	110
5/3/76	16	20	250	130	5	-	-	660	350	260	150	170	120
5/4/76	16	20	310	120	12	43	4	670	340	210	150	130	120
5/5/76	16	19	240	120	10	-	-	580	340	250	150	150	120
5/10/76	16	18	280	150	15	-	-	300	550	240	140	200	110
5/11/76	16	19	220	140	29	-	-	590	340	250	160	150	130
5/12/76	16	36	230	90	25	39	17	700	360	190	160	120	130
5/17/76	16	39	220	130	27	66	12	530	290	190	97	95	68
5/18/76	16	38	310	160	33	-	-	610	310	200	110	150	69
5/19/76	16[b]	38	300	160	51	-	-	790	390	250	120	180	79
5/24/76	19	35	300	180	12	-	-	470	250	140	88	110	56
5/25/76	21	33	220	110	19	-	-	420	250	150	77	92	53
5/26/76	21	30	130	170	14	61	4	540	290	170	85	110	51
5/31/76	15	37	150	70	21	29	15	550	160	290	68	78	57
6/1/76	20	30	210	170	21	-	-	450	150	190	55	70	43
6/2/76	17	36	220	81	17	-	-	460	160	150	56	86	45
6/7/76	21	30	230	140	34	-	-	-	-	-	-	-	-
6/8/76	20	20	-	110	21	71	12	-	-	-	-	-	-
6/9/76	15	37	230	140	18	-	-	-	-	-	-	-	-
6/14/76	19	34	270	190	34	-	-	520	310	190	100	160	66
6/15/76	19	46	300	180	22	-	-	500	300	140	91	140	63
6/16/76	19	53	270	160	26	83	14	490	300	190	95	140	62
6/21/76	24	48	380	190	44	-	-	620	350	180	130	170	78
6/22/76	13	48	240	120	23	75	9	530	310	170	110	130	75
6/23/76	19	50	310	150	39	-	-	530	270	180	120	110	68
6/28/76	21	39	300	110	26	34	12	620	230	120	91	82	59
6/29/76	20	42	240	110	-	-	-	580	230	130	-	68	-
6/30/76	16	46	320	120	26	-	-	620	230	150	86	73	66
7/5/76	12	47	170	81	30	-	-	450	190	160	72	62	47
7/6/76	18	43	260	100	32	-	-	490	210	180	81	84	56
7/7/76	19	35	300	150	21	56	10	620	260	140	80	100	55
7/12/76	-	-	290	140	26	86	17	610	290	190	100	140	72
7/13/76	-	-	260	140	28	-	-	600	300	190	110	69	95
7/14/76	-	-	360	200	39	-	-	680	320	170	91	100	60
7/19/76	23	37	350	200	27	-	-	690	390	250	120	160	87
7/20/76	18	43	300	190	26	54	12	610	290	200	120	100	92
7/21/76	-	-	240	78	17	-	-	830	200	180	100	67	72
7/26/76	20	51	320	150	24	-	-	680	280	160	100	120	73
7/27/76	18	47	350	150	38	-	-	620	290	160	110	75	75
7/28/76	19	41	320	170	40	46	23	480	250	160	100	74	72
8/2/76	44	26	570	310	100	220	51	880	460	410	280	310	200
8/3/76	44	24	780	390	150	-	-	900	560	410	340	290	240
8/4/76	40	23	520	260	110	-	-	930	540	480	320	260	230

(continued on next page)

TABLE E-1. (continued)

Date	Flow, mgd		BOD$_5$, mg/l			Soluble BOD$_5$, mg/l		COD, mg/l				Soluble COD, mg/l	
	Infl.	Recyc.	Raw Infl.	Prim. Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.
8/9/76	29	35	470	270	120	-	-	930	500	280	200	170	120
8/10/76	40	21	680	300	170	180	130	970	480	340	270	150	140
8/11/76	42	19	670	350	230	-	-	1,060	580	300	330	300	160
8/16/76	40	-	620	330	140	-	-	980	600	390	260	280	140
8/17/76	41	26	690	350	160	-	-	1,170	650	450	290	330	150
8/18/76	42	23	720	330	150	250	130	1,150	570	450	190	350	160
8/23/76	40	23	620	370	120	220	82	1,080	540	340	190	320	140
8/24/76	41	24	680	320	140	-	-	1,180	480	260	320	340	150
8/25/76	41	23	540	260	83	-	-	1,140	510	300	240	340	120
8/30/76	40	24	530	280	66	-	-	980	470	300	220	300	110
8/31/76	43	-	720	300	114	210	71	1,270	500	280	270	310	150
9/1/76	42	21	470	240	142	-	-	990	440	420	230	300	130
9/6/76	24	46	160	57	21	-	-	530	250	110	140	96	82
9/7/76	40	30	-	-	-	-	-	850	420	340	200	280	98
9/8/76	42	24	630	280	68	-	-	-	-	-	-	-	-
9/13/76	37	28	470	270	34	220	30	850	440	220	160	330	97
9/14/76	38	31	460	260	54	-	-	930	420	240	200	270	110
9/15/76	37	27	480	260	56	-	-	930	500	280	210	320	120
9/20/76	36	20	430	250	40	-	-	1,060	490	230	200	320	120
9/21/76	36	20	410	230	46	150	24	800	430	250	180	250	110
9/22/76	38	21	380	240	43	-	-	1,030	490	220	190	280	110
9/27/76	31	29	380	270	37	-	-	880	490	230	200	310	110
9/28/76	34	24	370	210	118	-	-	980	430	230	210	270	120
9/29/76	31	26	450	270	53	180	24	1,030	570	360	250	290	120
10/4/76	29	24	490	250	43	160	24	1,340	500	240	180	270	98
10/5/76	30	24	710	340	65	-	-	1,330	610	430	230	380	120
10/6/76	23	30	530	280	63	-	-	1,060	500	240	220	310	110
10/11/76	23	26	380	230	43	-	-	770	430	250	190	210	81
10/12/76	20	31	390	210	29	120	16	710	380	230	150	200	72
10/13/76	19	34	240	200	33	-	-	670	370	240	170	190	80
10/18/76	23	27	350	160	21	-	-	650	280	160	120	150	63
10/19/76	19	34	380	190	25	-	-	710	340	210	130	200	75
10/20/76	18	34	370	200	26	110	12	700	350	210	140	190	80
10/25/76	15	39	190	140	13	70	6	610	270	140	84	150	58
10/26/76	12	45	280	170	16	-	-	670	330	140	92	180	66
10/27/76	18	50	300	190	18	-	-	670	360	160	96	200	77
11/1/76	17	50	230	200	17	-	-	630	320	140	93	140	54
11/2/76	17	48	300	190	13	140	7	650	320	150	77	220	55
11/3/76	17	46	320	210	13	-	-	610	300	140	78	150	52
11/8/76	18	52	200	170	12	-	-	430	290	140	61	130	56
11/9/76	18	49	330	200	12	-	-	600	360	130	69	180	64
11/10/76	13	55	-	-	-	-	-	-	-	-	-	-	-
11/15/76	18	57	330	210	17	100	10	670	320	210	110	150	64
11/16/76	18	57	380	340	42	-	-	770	380	320	140	150	88
11/17/76	18	54	400	210	31	-	-	850	390	220	130	180	89
11/22/76	18	58	330	210	27	-	-	650	320	170	120	160	80
11/23/76	19	58	-	-	-	-	-	-	-	-	-	-	-
11/24/76	18	59	-	-	-	-	-	-	-	-	-	-	-
11/29/76	19	27	420	220	33	-	-	1,000	490	220	160	170	90
11/30/76	19	32	410	240	50	110	22	770	430	200	170	190	93
12/1/76	19	32	370	210	29	-	-	740	380	160	120	210	88
12/6/76	18	58	350	240	18	-	-	850	310	150	95	140	61
12/7/76	18	32	510	250	20	-	-	860	380	110	93	180	63
12/8/76	18	32	440	210	19	79	9	750	340	140	100	160	62
12/13/76	19	30	440	220	16	100	11	830	420	250	100	240	63
12/14/76	19	30	480	280	29	-	-	720	450	230	150	200	88
12/15/76	18	31	360	210	-	-	-	690	370	210	110	160	62
12/20/76	19	60	340	210	18	-	-	760	420	300	120	190	70
12/21/76	19	50	450	200	21	110	9	930	400	250	110	200	77
12/22/76	19	50	-	-	-	-	-	-	-	-	-	-	-
12/27/76	16	49	520	240	19	-	-	1,060	430	180	80	190	58
12/28/76	15	51	510	300	12	-	-	790	370	140	61	200	53
12/29/76	21	44	-	-	-	-	-	-	-	-	-	-	-

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TABLE E-1. (continued)

Date	Flow, mgd		BOD$_5$, mg/l			Soluble BOD$_5$, mg/l		COD, mg/l				Soluble COD, mg/l	
	Infl.	Recyc.	Raw Infl.	Prim. Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Sec. Effl.
1/3/77	18	51	380	210	14	-	-	860	420	190	110	220	56
1/4/77	19	48	350	300	17	-	-	700	400	230	97	170	67
1/5/77	19	52	460	240	15	160	8	1,030	490	190	98	260	77
1/10/77	19	52	300	240	12	180	6	720	400	110	84	280	54
1/11/77	20	50	410	250	11	-	-	1,050	420	130	87	260	58
1/12/77	20	51	420	140	22	-	-	780	230	210	120	99	82
1/17/77	20	48	380	-	13	-	-	850	230	210	110	89	62
1/18/77	19	48	410	180	17	90	8	890	340	240	91	180	67
1/19/77	17	52	390	-	18	-	-	950	330	270	150	130	85
1/24/77	19	49	240	210	12	-	-	510	320	160	100	210	68
1/25/77	19	50	250	-	17	-	-	370	150	370	97	53	67
1/26/77	19	52	350	220	16	130	8	750	320	160	110	210	77
1/31/77	18	51	440	230	14	92	7	1,070	440	160	110	190	64
2/1/77	18	59	300	180	19	-	-	710	360	220	130	180	67
2/2/77	18	57	460	200	11	-	-	870	390	200	110	180	69
2/7/77	18	31	340	190	29	-	-	630	300	140	85	130	63
2/8/77	-	-	280	190	23	67	11	580	320	170	87	100	70
2/9/77	18	32	320	160	18	-	-	640	300	100	89	120	65
2/14/77	19	55	460	180	11	-	-	950	460	210	130	120	63
2/15/77	19	53	470	130	15	-	-	940	200	180	110	110	65
2/16/77	18	53	360	-	10	-	5	670	210	300	100	71	64
2/21/77	18	54	170	160	11	100	4	400	320	320	130	200	68
2/22/77	18	52	570	240	11	-	-	1,300	220	160	110	250	65
2/23/77	18	47	570	-	12	-	-	960	220	440	130	74	76
2/28/77	18	50	290	-	12	-	-	650	160	330	86	49	57
3/1/77	23	45	340	170	13	38	7	700	370	150	92	130	71
3/2/77	18	49	390	41	12	-	-	690	97	440	97	63	70
3/7/77	17	50	370	160	15	-	-	860	280	230	92	97	71
3/8/77	17	55	380	260	12	-	-	630	460	130	69	170	58
3/9/77	18	50	370	190	14	95	6	650	320	84	72	160	63
3/14/77	16	53	340	150	15	28	9	1,040	440	240	100	94	63
3/15/77	19	55	370	200	13	-	-	730	500	180	100	120	54
3/16/77	19	57	320	190	19	-	-	680	480	200	110	170	67

[a] mgd x 3,785 = m^3/day.

[b] Flow meter inoperative; estimated flow.

TABLE E-2. DAILY VALUES FOR SUSPENDED SOLIDS, VOLATILE SUSPENDED SOLIDS, WATER TEMPERATURE, pH, DISSOLVED OXYGEN, AND ALKALINITY

Date	Suspended solids, mg/l				Volatile suspended solids, mg/l				Water temperature, C		pH		Dissolved oxygen, mg/l	Alkalinity, mg/l as $CaCO_3$	
	Raw Infl.	Prim. Effl	Filter Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Filter Effl.	Prim. Effl.	Filter Effl.	Filter Effl.	Prim. Effl.	Sec. Effl.
3/15/76	300	220	140	42	210	160	84	29	25	24	6.4	7.3	6.4	200	110
3/16/76	500	170	210	42	360	96	110	35	26	26	6.7	7.4	7.0	-	130
3/17/76	460	220	120	31	340	140	60	27	26	26	6.7	7.3	5.6	-	120
3/22/76	380	320	110	37	320	260	96	28	25	24	7.1	7.6	6.4	-	110
3/23/76	380	150	96	37	300	120	64	37	26	24	6.6	7.4	6.1	200	140
3/24/76	-	150	120	28	-	110	110	24	26	24	6.8	7.7	5.2	-	150
3/29/76	270	100	120	28	230	72	96	23	25	21	7.1	7.8	6.8	-	130
3/30/76	290	230	180	32	220	170	120	18	26	25	7.0	7.8	6.5	-	140
3/31/76	270	270	140	52	210	200	96	32	25	24	6.8	7.8	6.6	200	150
4/5/76	300	120	130	21	250	110	110	17	-	-	7.1	8.0	7.6	220	160
4/6/76	240	190	140	28	200	150	110	19	26	24	6.9	7.8	6.3	-	130
4/7/76	320	270	220	-	250	170	160	-	26	23	6.9	7.9	6.4	-	-
4/12/76	250	120	160	24	220	120	140	23	-	-	-	-	-	-	110
4/13/76	210	160	130	25	170	130	120	21	-	-	-	-	-	200	110
4/14/76	350	190	150	26	310	170	110	24	-	-	-	-	-	-	110
4/19/76	330	130	200	29	260	96	140	20	26	24	7.0	6.3	7.0	-	65
4/20/76	280	110	120	32	210	90	92	24	27	25	6.9	7.3	7.0	-	98
4/21/76	270	120	100	22	210	100	80	17	27	25	7.0	7.6	6.2	190	110
4/26/76	200	84	110	30	180	84	52	30	24	22	7.2	7.6	7.7	190	86
4/27/76	280	130	92	30	260	130	92	26	27	25	6.8	7.4	7.7	-	78
4/28/76	290	170	92	25	270	170	92	23	-	-	-	-	7.7	-	81
5/3/76	340	110	150	27	260	80	100	17	28	26	7.0	7.4	4.2	-	100
5/4/76	-	-	-	-	-	-	-	-	27	27	8.6	8.1	6.2	-	-
5/5/76	380	160	140	26	300	130	100	19	27	25	7.3	7.7	6.4	-	94
5/10/76	72	320	140	22	68	260	92	16	27	26	7.1	7.5	6.3	-	46
5/11/76	260	120	150	33	200	96	130	25	28	27	6.7	7.1	6.2	-	110
5/12/76	240	140	84	16	180	110	64	14	29	29	6.9	7.3	4.3	180	120
5/17/76	300	60	120	18	200	60	100	17	29	27	7.1	7.6	5.2	200	160
5/18/76	290	160	170	44	240	100	84	27	29	27	6.7	7.6	-	-	160
5/19/76	760	180	220	25	550	100	110	15	-	-	-	-	5.5	-	160
5/24/76	420	140	150	32	300	84	88	21	28	26	7.1	7.6	6.6	-	140
5/25/76	140	140	180	22	96	100	110	20	28	27	7.0	8.1	5.4	-	140
5/26/76	280	140	190	25	210	100	140	23	28	27	7.1	8.1	5.4	190	140
5/31/76	330	39	280	11	220	31	170	9	-	-	-	-	-	210	130
6/1/76	440	57	180	7	320	46	110	6	28	27	9.3	8.6	6.4	-	170
6/2/76	280	60	160	20	210	48	92	11	28	27	7.2	7.7	6.3	-	130
6/7/76	340	150	170	90	230	88	120	60	-	-	-	-	-	-	120
6/8/76	-	120	130	56	-	88	40	48	28	27	7.1	7.7	6.0	190	92
6/9/76	340	130	140	32	240	84	96	24	29	28	6.8	7.5	6.0	-	110
6/14/76	450	96	140	23	290	80	110	16	30	28	6.9	7.8	6.0	-	110
6/15/76	250	80	120	25	180	72	84	18	-	-	-	-	-	-	100
6/16/76	260	94	160	26	190	60	96	21	-	-	-	-	-	210	100
6/21/76	300	140	200	42	250	100	160	32	28	27	6.9	7.6	6.7	-	95
6/22/76	280	200	130	40	200	160	96	29	28	27	6.9	7.6	6.4	180	110
6/23/76	250	110	130	140	210	100	110	120	29	28	6.7	7.4	6.4	-	92
6/28/76	400	140	80	30	290	92	44	18	-	-	-	-	-	190	110
6/29/76	320	160	110	-	240	110	76	-	30	30	6.7	7.2	5.8	-	-
6/30/76	240	200	80	17	180	140	44	11	-	-	-	-	-	-	110
7/5/76	270	100	140	5	180	[illegible]	96	4	-	-	-	-	-	-	92
7/6/76	500	130	88	20	380	96	48	12	30	29	7.1	7.8	-	-	120
7/7/76	350	120	110	17	260	84	72	11	-	-	-	-	-	200	130
7/12/76	410	120	240	32	320	120	240	29	28	27	8.7	8.0	5.1	240	150
7/13/76	410	160	130	32	310	160	130	32	30	-	7.0	-	-	-	150
7/14/76	400	180	220	33	290	180	210	27	-	-	-	-	-	-	170
7/19/76	500	160	190	21	350	110	140	18	28	28	-	-	-	-	230
7/20/76	440	130	150	29	290	100	100	19	30	29	6.8	8.0	-	230	160
7/21/76	440	96	170	8	310	96	120	8	30	29	6.7	7.7	5.5	-	120
7/26/76	750	140	110	20	300	96	72	14	31	29	6.5	7.5	5.6	-	120
7/27/76	480	160	120	30	290	150	120	30	31	30	6.6	7.5	3.8	-	130
7/28/76	430	160	130	29	260	160	120	23	30	30	-	-	-	200	130
8/2/76	520	160	180	38	340	160	170	36	-	-	-	-	-	350	300
8/3/76	520	240	190	44	370	230	180	42	30	28	9.5	8.3	4.2	-	340
8/4/76	580	260	280	36	390	230	230	32	-	-	-	-	-	-	290

(continued on next page)

TABLE E-2. (continued)

Date	Suspended solids, mg/l				Volatile suspended solids, mg/l				Water temperature, C		pH		Dissolved oxygen, mg/l	Alkalinity, mg/l as $CaCO_3$	
	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Filter Effl.	Prim. Effl.	Filter Effl.	Filter Effl.	Prim. Effl.	Sec. Effl.
8/9/76	500	250	140	38	290	210	110	30	29	29	9.0	9.1	1.2	-	300
8/10/76	610	190	190	21	360	160	160	21	31	31	6.2	8.0	-	370	340
8/11/76	740	200	200	32	450	180	180	32	29	29	9.2	8.3	-	-	400
8/16/76	720	300	270	62	510	260	250	62	29	29	8.9	8.3	1.2	-	390
8/17/76	700	310	320	58	500	270	280	58	-	-	-	-	-	-	410
8/18/76	840	280	300	82	560	230	270	82	-	-	-	-	-	500	460
8/23/76	1,000	180	270	54	580	180	250	54	-	-	-	-	-	370	370
8/24/76	1,010	200	220	68	590	180	190	58	30	30	5.9	7.6	0	-	370
8/25/76	880	150	120	60	420	130	100	54	30	30	9.1	8.3	1.2	-	390
8/30/76	910	160	180	58	680	150	160	54	30	30	9.5	8.2	0.5	-	370
8/31/76	900	170	160	58	640	130	130	46	-	-	-	-	-	430	410
9/1/76	510	210	140	58	300	180	120	52	30	30	8.6	8.2	1.4	-	400
9/6/76	500	130	92	36	280	110	72	31	-	-	-	-	-	-	260
9/7/76	-	-	-	-	-	-	-	-	30	30	10.3	8.4	0	-	-
9/8/76	540	130	184	50	170	100	170	45	30	29	6.9	7.9	1.0	-	340
9/13/76	500	96	120	30	320	96	84	20	30	29	9.8	8.5	3.1	340	280
9/14/76	640	110	120	24	410	110	100	24	-	-	-	-	-	-	360
9/15/76	600	160	200	44	400	150	140	44	30	30	9.3	8.5	-	-	350
9/20/76	660	130	200	48	430	92	150	32	29	29	8.2	8.1	5.2	-	290
9/21/76	510	160	160	56	300	130	110	32	-	-	-	-	-	380	300
9/22/76	540	160	180	60	340	120	150	48	-	-	8.7	8.2	4.4	-	320
9/27/76	470	120	96	34	330	120	96	34	29	28	9.9	8.5	6.1	-	340
9/28/76	670	110	130	38	410	100	100	38	-	-	-	-	-	-	280
9/29/76	840	200	220	50	550	180	200	50	29	28	8.6	8.1	4.6	400	350
10/4/76	890	200	230	66	270	140	180	54	-	-	-	-	-	380	320
10/5/76	800	230	290	64	530	170	210	48	28	28	8.2	8.1	6.0	-	360
10/6/76	960	160	200	62	520	140	160	60	-	-	-	-	-	-	430
10/11/76	550	190	200	60	380	160	170	50	28	28	7.1	7.7	5.8	-	300
10/12/76	380	120	180	44	290	120	170	44	28	28	-	-	-	250	180
10/13/76	500	180	110	46	360	140	96	46	-	-	-	-	-	-	190
10/18/76	320	130	140	38	260	120	120	38	28	28	6.9	7.5	6.2	-	140
10/19/76	360	120	120	56	290	110	100	54	-	-	-	-	-	-	140
10/20/76	360	150	200	40	300	150	160	40	28	28	6.7	7.2	6.5	220	130
10/25/76	370	110	92	24	280	72	68	22	-	-	-	-	-	190	80
10/26/76	320	88	60	22	240	68	44	20	-	-	-	-	-	-	120
10/27/77	380	76	64	44	310	56	56	40	28	25	7.2	7.0	7.0	-	140
11/1/76	300	160	110	24	220	140	88	24	-	-	7.1	7.0	-	-	66
11/2/76	300	60	130	20	240	56	96	18	27	25	6.9	6.7	6.6	180	82
11/3/76	400	100	96	24	300	68	80	12	28	26	-	-	6.4	-	81
11/8/76	240	84	96	28	230	84	96	28	-	-	-	-	-	-	76
11/9/76	320	120	84	20	290	120	84	20	28	27	-	-	-	-	80
11/11/76	-	-	-	-	-	-	-	-	-	-	6.9	6.7	-	-	-
11/15/76	420	130	160	42	320	110	140	40	27	25	7.0	6.4	5.6	220	55
11/16/76	520	200	270	38	420	170	220	36	28	26	6.6	7.2	6.6	-	66
11/17/76	460	140	190	34	370	130	150	34	25	24	6.8	7.4	5.6	-	.75
11/22/76	430	140	140	46	360	140	130	46	25	22	6.8	7.4	6.6	-	100
11/23/76	-	-	-	-	-	-	-	-	26	23	6.9	7.7	-	-	-
11/24/76	-	-	-	-	-	-	-	-	25	22	6.9	7.8	-	-	-
11/29/76	460	200	160	60	380	150	110	44	25	23	7.1	7.5	7.8	-	140
11/30/76	420	140	150	58	320	120	120	46	-	-	-	-	-	230	190
12/1/76	280	120	100	22	240	110	84	20	25	23	6.8	7.7	5.6	-	180
12/6/76	400	170	170	34	310	130	120	26	23	20	7.0	7.4	6.0	-	110
12/7/76	370	140	60	28	300	120	56	28	23	22	6.9	7.5	5.7	-	-
12/8/76	370	140	88	30	280	120	68	22	-	-	-	-	-	-	-
12/13/76	350	92	100	12	280	88	92	12	23	21	6.9	7.4	-	250	110
12/14/76	330	130	120	14	270	110	110	14	23	22	7.0	7.3	6.0	-	130
12/15/76	270	150	190	24	230	120	160	24	23	21	6.9	7.6	6.1	-	110
12/20/76	370	170	230	34	300	160	190	34	23	21	7.0	7.4	7.4	-	72
12/21/76	470	110	170	28	400	110	140	28	-	-	6.9	7.6	6.0	240	88
12/22/76	-	-	-	-	-	-	-	-	24	21	7.2	7.1	7.0	-	-

(continued on next page)

TABLE E-2. (continued)

Date	Suspended solids, mg/l				Volatile suspended solids, mg/l				Water temperature, C		pH		Dissolved oxygen, mg/l	Alkalinity, mg/l as $CaCO_3$	
	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Filter Effl.	Sec. Effl.	Prim. Effl.	Filter Effl.	Prim. Effl.	Filter Effl.	Filter Effl.	Prim. Effl.	Sec. Effl.
12/27/76	580	180	160	22	470	140	110	20	-	-	7.6	7.6	-	-	61
12/28/76	580	110	130	-	460	96	100	-	21	18	7.2	7.7	7.6	-	78
12/29/76	-	-	-	-	-	-	-	-	21	19	6.9	7.2	7.0	-	-
1/3/77	330	110	160	28	260	96	100	26	20	19	7.3	7.8	6.9	-	34
1/4/77	300	120	120	18	260	96	100	17	22	20	6.7	7.0	7.2	-	80
1/5/77	870	100	100	13	680	76	100	13	21	19	6.7	7.3	7.4	250	86
1/10/77	470	130	140	52	340	84	80	30	22	19	6.5	6.9	6.8	220	27
1/11/77	750	120	140	27	600	92	96	20	22	19	6.5	7.1	7.8	-	78
1/12/77	420	110	140	26	310	96	120	22	21	19	6.6	7.0	7.0	-	84
1/17/77	500	130	170	46	330	68	100	30	22	18	6.5	6.9	7.8	-	69
1/18/77	470	160	160	36	330	120	120	34	-	-	-	-	-	190	70
1/19/77	410	150	190	40	300	110	150	28	22	19	6.6	6.9	7.4	-	70
1/24/77	260	84	150	24	220	84	140	24	24	20	-	-	-	-	48
1/25/77	200	92	56	14	190	92	56	14	23	21	6.5	7.0	7.0	-	65
1/26/77	520	88	120	36	440	88	120	36	24	20	6.5	7.0	7.0	170	59
1/31/77	680	180	110	24	520	150	80	18	22	20	6.8	7.2	7.4	230	46
2/1/77	360	92	130	20	280	76	96	20	-	-	-	-	-	-	62
2/2/77	480	140	150	12	330	96	96	6	23	20	6.7	7.1	7.6	-	44
2/7/77	330	130	140	22	250	76	72	10	23	23	6.8	7.1	5.6	-	75
2/8/77	290	150	110	15	220	92	64	9	22	21	7.3	7.9	14.6	210	100
2/9/77	280	160	92	14	220	120	52	6	23	21	7.2	6.4	7.8	-	89
2/14/77	440	240	130	24	370	200	110	24	24	24	6.7	7.2	6.7	-	35
2/15/77	570	140	96	20	460	100	72	20	25	24	6.9	7.2	7.2	-	69
2/16/77	310	-	170	19	250	-	120	16	24	24	6.6	7.0	7.9	-	46
2/21/77	170	420	150	25	120	370	130	24	-	-	6.9	7.3	-	200	48
2/22/77	1,070	100	180	23	850	88	130	21	24	21	6.9	7.3	8.2	-	42
2/23/77	380	-	300	18	300	-	280	18	23	20	-	-	8.9	-	58
2/28/77	260	-	230	6	220	-	190	6	24	20	6.7	7.0	7.8	-	39
3/1/77	290	190	100	15	260	170	92	15	24	20	6.5	7.3	7.6	230	64
3/2/77	230	-	160	18	190	-	150	11	20	19	6.8	6.2	6.8	-	88
3/7/77	540	240	180	26	400	180	140	20	25	23	6.6	7.4	7.7	-	19
3/8/77	420	330	130	29	280	250	68	14	25	24	6.7	7.2	8.4	-	65
3/9/77	410	150	120	17	270	100	76	6	-	-	-	-	-	210	66
3/14/77	630	230	250	32	470	160	170	21	25	23	6.2	7.3	7.1	210	37
3/15/77	390	320	140	39	310	270	110	31	-	-	-	-	-	-	45
3/16/77	370	190	140	30	280	150	120	28	22	21	7.0	7.5	6.4	-	43

TABLE E-3. DAILY VALUES FOR PHOSPHORUS, TOTAL KJELDAHL NITROGEN, AMMONIA NITROGEN, AND NITRATE NITROGEN

Date	Total phosphorus, mg/l			Total Kjeldahl nitrogen, mg/l			Ammonia nitrogen, mg/l			Nitrite nitrogen, mg/l			Nitrate nitrogen, mg/l		
	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.
3/15/76	10	7.8	6.8	25	25	17	16	15	8.6	<0.1	<0.1	0.2	<0.1	<0.1	0.4
3/16/76	8.1	6.9	6.2	31	25	17	15	11	10	<0.1	<0.1	0.2	<0.1	<0.1	0.3
3/17/76	8.0	6.2	5.4	33	22	15	16	12	7.6	<0.1	<0.1	0.1	<0.1	<0.1	0.3
3/22/76	7.4	6.9	4.9	37	39	13	16	14	6.1	<0.1	<0.1	0.1	<0.1	<0.1	0.2
3/23/76	7.9	6.0	5.2	36	27	17	20	16	9.6	<0.1	<0.1	0.2	<0.1	<0.1	0.2
3/24/76	-	6.1	5.9	-	27	17	-	15	11	-	0.1	0.2	-	<0.1	0.3
3/29/76	5.6	6.0	5.8	25	26	15	16	12	9.7	<0.1	<0.1	0.2	<0.1	<0.1	0.3
3/30/76	6.0	5.9	5.8	25	28	16	16	15	10	<0.1	<0.1	0.1	<0.1	<0.1	0.3
3/31/76	6.9	6.7	6.2	30	26	19	22	14	12	<0.1	<0.1	0.2	<0.1	<0.1	0.2
4/5/76	7.5	8.1	6.7	24	32	20	17	20	11	<0.1	<0.1	0.2	<0.1	<0.1	0.3
4/6/76	6.6	6.8	5.6	29	29	16	15	14	8.1	0.1	<0.1	0.2	0.1	<0.1	0.2
4/7/76	6.6	5.5	-	32	30	-	20	16	-	<0.1	<0.1	-	<0.1	<0.1	-
4/12/76	5.9	5.3	5.3	25	20	11	20	15	5.7	<0.1	<0.1	0.3	0.1	0.1	0.5
4/13/76	5.6	6.0	5.6	25	23	9.4	18	15	4.7	0.1	0.1	0.2	<0.1	<0.1	0.5
4/14/76	7.0	6.7	5.6	27	28	9.8	18	17	5.4	<0.1	<0.1	0.3	<0.1	<0.1	0.5
4/19/76	8.8	6.9	6.7	29	22	6.9	16	14	2.4	0.1	0.1	0.1	0.1	0.1	1.0
4/20/76	6.0	5.5	5.2	22	22	7.9	11	14	1.4	0.1	0.1	0.3	0.1	0.1	0.7
4/21/76	6.6	5.6	5.2	25	20	8.1	12	11	1.6	0.1	0.1	0.4	0.1	0.1	0.6
4/26/76	7.1	6.5	5.9	22	19	4.9	14	13	1.8	<0.1	<0.1	0.1	<0.1	<0.1	10
4/27/76	11	8.4	8.1	22	19	2.2	14	13	2.3	<0.1	<0.1	<0.1	<0.1	<0.1	7.2
4/28/76	8.4	8.0	7.3	28	22	5.3	15	13	1.4	<0.1	<0.1	<0.1	<0.1	<0.1	7.5
5/3/76	8.5	7.4	7.0	33	31	12	26	22	6.7	<0.1	<0.1	<0.1	<0.1	<0.1	8.9
5/4/76	11	8.9	6.7	34	28	10	15	18	5.4	<0.1	<0.1	<0.1	<0.1	<0.1	8.1
5/5/76	8.6	7.8	8.5	35	34	11	17	17	4.7	<0.1	<0.1	<0.1	0.1	<0.1	7.3
5/10/76	5.8	5.4	4.5	19	27	5.5	12	16	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	4.3
5/11/76	6.2	5.7	5.2	23	24	9.3	9.3	13	3.6	<0.1	<0.1	0.1	<0.1	<0.1	3.8
5/12/76	5.7	5.1	5.1	24	21	10	9.0	10	5.1	<0.1	<0.1	0.1	0.1	0.1	2.4
5/17/76	7.0	6.8	5.5	28	24	13	13	14	7.7	<0.1	<0.1	0.4	<0.1	<0.1	3.1
5/18/76	6.4	5.6	4.9	29	24	12	12	14	7.8	<0.1	<0.1	0.5	<0.1	<0.1	2.2
5/19/76	7.2	5.8	4.6	33	25	12	13	15	7.4	<0.1	<0.1	0.5	<0.1	<0.1	1.7
5/24/76	6.6	5.7	4.8	27	22	10	13	15	7.0	<0.1	<0.1	0.6	0.1	0.1	5.8
5/25/76	7.3	6.0	5.3	26	21	8.9	12	14	5.9	<0.1	<0.1	0.6	0.1	0.1	5.7
5/26/76	6.7	5.6	4.6	27	22	8.5	11	13	5.3	<0.1	<0.1	0.6	0.2	0.1	5.3
5/31/76	7.1	6.0	5.3	26	23	12	11	16	8.2	<0.1	<0.1	0.8	<0.1	<0.1	6.8
6/1/76	6.6	4.4	4.1	29	20	8.1	12	14	5.7	<0.1	<0.1	0.7	0.2	<0.1	4.6
6/2/76	6.2	6.2	5.4	29	21	8.5	14	16	6.4	<0.1	<0.1	0.7	0.1	<0.1	5.0
6/7/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6/8/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6/9/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6/14/76	6.6	7.0	6.3	27	23	8.5	17	17	3.6	<0.1	<0.1	0.7	0.2	<0.1	0.9
6/15/76	6.7	7.5	6.4	23	25	9.9	16	16	3.1	<0.1	<0.1	1.0	<0.1	<0.1	0.1
6/16/76	5.5	6.4	6.2	21	24	7.5	9.8	17	2.8	<0.1	<0.1	0.5	<0.1	<0.1	0.7
6/21/76	6.5	7.8	6.6	27	22	8.6	17	15	2.8	<0.1	<0.1	0.4	<0.1	<0.1	1.8
6/22/76	6.0	6.0	5.8	24	19	8.5	14	17	3.3	0.1	<0.1	0.5	<0.1	0.5	0.9
6/23/76	6.2	6.0	5.4	24	20	8.5	14	12	3.3	0.1	0.1	0.3	<0.1	<0.1	0.7
6/28/76	11	12	11	25	19	12	15	13	4.5	<0.1	<0.1	0.5	0.1	<0.1	2.1
6/29/76	6.1	6.0	-	24	19	-	18	14	-	<0.1	<0.1	-	<0.1	<0.1	-
6/30/76	7.0	6.7	6.2	25	23	9.4	17	15	4.2	<0.1	<0.1	0.4	0.1	<0.1	1.2
7/5/76	8.9	6.9	7.4	34	30	9.8	23	25	5.6	<0.1	<0.1	0.9	0.1	0.1	3.2
7/6/76	7.9	6.0	5.9	27	16	4.9	17	11	1.8	<0.1	<0.1	0.3	0.1	<0.1	1.0
7/7/76	5.8	5.5	4.7	23	18	-	17	9.9	2.2	<0.1	<0.1	0.2	0.1	<0.1	0.5
7/12/76	9.4	7.4	6.4	30	23	8.4	17	13	2.9	0.1	0.1	0.3	<0.1	<0.1	1.4
7/13/76	7.8	6.5	6.3	25	19	7.6	15	12	2.8	0.1	0.1	0.2	<0.1	<0.1	0.5
7/14/76	6.7	5.5	4.7	21	20	7.1	15	11	2.0	0.1	0.1	0.2	<0.1	<0.1	0.3
7/19/76	7.0	5.4	3.3	34	29	8.2	15	13	1.6	<0.1	<0.1	0.1	0.1	<0.1	0.2
7/20/76	7.1	5.4	5.4	36	27	11	17	16	8.0	<0.1	<0.1	0.2	0.1	<0.1	0.5
7/21/76	8.7	5.8	6.1	36	25	14	19	15	6.7	<0.1	<0.1	0.2	0.1	0.1	0.8
7/26/76	8.0	5.9	5.8	35	26	11	19	15	6.4	<0.1	<0.1	0.1	<0.1	<0.1	0.6
7/27/76	6.6	5.3	5.2	30	30	18	19	18	10	<0.1	<0.1	0.1	<0.1	<0.1	0.4
7/28/76	7.9	5.8	5.6	26	22	16	19	17	9.7	<0.1	<0.1	0.1	<0.1	<0.1	0.3
8/2/76	4.6	2.3	1.3	28	31	21	9.8	17	8.8	<0.1	<0.1	[illegible]	[illegible]	<0.1	<0.1
8/3/76	4.7	2.5	1.7	29	41	30	8.3	23	15	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
8/4/76	5.3	3.2	1.9	33	38	25	11	17	10	<0.1	<0.1	0.2	<0.1	<0.1	<0.1

(continued on next page)

TABLE E-3. (continued)

Date	Total phosphorus, mg/l			Total Kjeldahl nitrogen, mg/l			Ammonia nitrogen, mg/l			Nitrite nitrogen, mg/l			Nitrate nitrogen, mg/l		
	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.
8/9/76	5.3	4.0	2.0	28	42	27	9.1	22	16	<0.1	<0.1	0.2	<0.1	<0.1	0.1
8/10/76	5.8	3.2	2.4	32	42	32	10	24	18	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
8/11/76	5.8	3.2	2.2	37	50	38	12	29	21	<0.1	<0.1	0.2	<0.1	0.1	<0.1
8/16/76	7.8	4.2	3.4	38	47	34	13	21	19	<0.1	<0.1	<0.1	0.1	<0.1	<0.1
8/17/76	6.4	4.6	2.8	49	52	34	16	25	18	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/18/76	6.9	4.1	2.6	40	55	41	19	32	25	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/23/76	6.4	2.6	1.5	42	35	27	11	19	14	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
8/24/76	5.8	3.1	2.2	37	35	30	9.1	19	14	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
8/25/76	6.7	3.7	2.8	32	40	34	9.9	25	20	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8/30/76	5.9	2.2	1.6	27	32	26	9.1	17	14	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
8/31/76	6.3	2.7	1.9	30	38	30	9.7	20	15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
9/1/76	7.5	3.7	2.6	34	40	32	11	26	21	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
9/6/76	7.6	4.0	4.7	27	34	32	15	23	21	<0.1	<0.1	0.7	<0.1	<0.1	0.1
9/7/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9/8/76	3.9	2.1	1.4	28	31	22	10	17	11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
9/13/76	7.8	2.9	2.3	27	19	12	14	9.7	3.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
9/14/76	6.2	3.1	1.7	24	25	14	12	11	4.9	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
9/15/76	5.7	3.1	2.7	22	29	21	12	11	7.0	<0.1	<0.1	0.3	<0.1	<0.1	<0.1
9/20/76	5.1	2.7	2.2	31	20	12	12	11	3.8	<0.1	<0.1	0.3	<0.1	<0.1	0.2
9/21/76	4.9	3.4	2.2	24	25	13	10	11	3.7	<0.1	<0.1	0.2	<0.1	<0.1	0.1
9/22/76	5.4	3.3	2.3	34	23	16	10	11	5.4	<0.1	<0.1	0.3	<0.1	<0.1	0.1
9/27/76	5.6	3.2	2.9	30	26	14	10	12	6.6	<0.1	<0.1	0.4	<0.1	<0.1	0.1
9/28/76	6.3	3.9	3.7	36	26	18	12	13	7.3	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
9/29/76	7.7	4.0	3.1	36	31	18	12	14	6.7	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
10/4/76	11	5.4	4.5	43	33	15	13	15	6.5	<0.1	<0.1	0.6	<0.1	<0.1	0.1
10/5/76	10	6.0	4.6	67	46	21	16	15	7.7	0.1	<0.1	0.6	<0.1	<0.1	<0.1
10/6/76	12	6.3	3.8	63	42	25	14	21	12	<0.1	<0.1	0.5	<0.1	<0.1	<0.1
10/11/76	6.2	4.4	3.2	27	25	13	10	12	5.6	<0.1	<0.1	0.4	<0.1	<0.1	0.2
10/12/76	6.9	5.6	4.9	33	27	18	16	18	9.1	<0.1	<0.1	0.7	<0.1	<0.1	0.2
10/13/76	8.1	6.4	5.5	37	32	18	15	19	11	<0.1	<0.1	0.8	<0.1	<0.1	0.1
10/18/76	8.4	6.3	6.1	31	27	15	17	17	8.0	<0.1	<0.1	0.8	0.1	0.1	0.7
10/19/76	11	6.1	5.7	54	31	20	19	17	8.7	<0.1	<0.1	0.7	0.1	0.1	0.3
10/20/76	7.0	6.1	4.9	33	27	16	17	16	6.9	<0.1	<0.1	0.6	<0.1	<0.1	0.2
10/25/76	6.3	6.7	6.1	31	24	9.4	17	15	4.1	<0.1	<0.1	0.3	0.1	0.1	1.1
10/26/76	5.8	7.1	6.0	29	28	11	17	17	5.7	<0.1	<0.1	0.2	0.1	0.1	0.6
10/27/76	5.6	6.9	6.1	29	27	12	19	18	6.1	<0.1	<0.1	0.4	<0.1	<0.1	0.5
11/1/76	7.4	8.3	8.2	33	33	7.4	19	22	1.6	0.1	<0.1	0.2	0.1	<0.1	1.9
11/2/76	7.0	5.8	6.9	37	26	6.8	22	18	1.8	<0.1	<0.1	0.1	<0.1	<0.1	1.2
11/3/76	6.7	7.3	6.9	32	33	9.5	20	23	2.9	<0.1	<0.1	0.1	<0.1	0.1	1.1
11/8/76	6.3	7.4	7.2	32	31	6.1	18	20	2.0	<0.1	<0.1	<0.1	0.1	0.1	1.3
11/9/76	6.2	6.8	6.3	33	32	6.4	16	19	1.1	<0.1	<0.1	<0.1	0.1	<0.1	0.7
11/10/76	8.6	7.3	5.9	36	29	8.7	-	-	-	-	-	-	-	-	-
11/15/76	8.6	7.3	5.9	36	29	8.7	18	18	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	1.5
11/16/76	13	9.1	6.8	43	34	12	20	19	4.3	<0.1	<0.1	0.1	<0.1	<0.1	1.4
11/17/76	13	8.7	7.0	41	33	13	20	21	5.8	<0.1	<0.1	0.4	0.1	<0.1	0.9
11/22/76	33	31	11	33	31	11	20	21	3.8	<0.1	<0.1	0.3	<0.1	<0.1	1.2
11/23/76	-	-	-	-	-	-	-	-	-	<0.1	<0.1	0.6	0.1	0.1	-
11/24/76	-	-	-	-	-	-	-	-	-	<0.1	<0.1	0.4	0.1	0.1	-
11/29/76	9.0	7.3	5.8	40	34	14	27	22	8.3	<0.1	<0.1	0.6	0.1	0.1	0.6
11/30/76	8.7	7.3	5.6	43	36	21	24	22	15	<0.1	<0.1	0.4	0.1	0.1	0.4
12/1/76	9.3	6.9	6.3	45	32	15	25	21	11	<0.1	<0.1	0.6	0.1	<0.1	0.3
12/6/76	9.9	8.2	7.7	38	29	40	25	20	5.5	<0.1	<0.1	0.5	<0.1	<0.1	<0.1
12/7/76	8.6	7.7	6.2	40	31	10	23	20	5.2	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
12/8/76	8.4	8.3	7.4	41	37	15	24	26	9.6	<0.1	<0.1	0.4	<0.1	<0.1	<0.1
12/13/76	8.9	7.9	7.4	57	52	10	25	23	3.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
12/14/76	8.7	7.8	6.7	53	47	30	27	26	7.3	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
12/15/76	8.3	8.1	7.0	37	37	8.4	24	21	2.1	0.3	<0.1	0.1	<0.1	<0.1	<0.1
12/20/76	29	9.3	8.7	35	36	6.8	17	19	2.0	<0.1	<0.1	<0.1	<0.1	<0.1	1.5
12/21/76	10	7.6	6.9	47	29	7.2	22	19	1.2	<0.1	<0.1	<0.1	<0.1	<0.1	1.2
12/22/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12/27/76	16	11	9.5	50	47	8.0	31	34	2.3	<0.1	<0.1	<0.1	<0.1	<0.1	3.1
12/28/76	13	9.6	8.6	65	40	5.9	34	29	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	1.8
12/29/76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(continued on next page)

TABLE E-3. (continued)

Date	Total phosphorus, mg/l			Total Kjeldahl nitrogen, mg/l			Ammonia nitrogen, mg/l			Nitrite nitrogen, mg/l			Nitrate nitrogen, mg/l		
	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	Sec. Effl.
1/3/77	11	9.1	5.4	56	44	8.9	33	29	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	2.4
1/4/77	9.5	8.5	7.0	49	44	6.3	24	27	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	1.4
1/5/77	11	7.8	5.6	81	48	6.4	36	29	0.9	<0.1	<0.1	<0.1	<0.1	<0.1	0.8
1/10/77	10	5.8	7.5	43	33	7.8	20	21	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	5.4
1/11/77	12	5.5	7.0	46	29	4.6	24	19	0.4	<0.1	<0.1	<0.1	<0.2	<0.1	3.1
1/12/77	8.4	-	5.7	45	-	7.2	20	-	0.2	<0.1	-	<0.1	<0.1	-	1.2
1/17/77	11	-	6.8	50	-	17	23	-	2.8	<0.1	-	<0.1	0.2	-	2.3
1/18/77	8.4	5.6	5.3	60	47	27	26	19	3.2	<0.1	<0.1	<0.1	0.2	0.2	1.5
1/19/77	11	-	5.8	56	-	30	26	-	3.9	<0.1	-	<0.1	0.2	-	1.4
1/24/77	6.2	5.7	6.8	44	42	37	16	19	3.2	<0.1	<0.1	<0.1	<0.1	<0.1	2.0
1/25/77	6.6	-	5.9	71	-	20	25	-	4.1	<0.1	-	<0.1	0.1	-	2.2
1/26/77	9.7	5.6	6.3	50	39	34	29	17	4.2	<0.1	<0.1	<0.1	0.1	<0.1	2.4
1/31/77	13	7.8	6.2	63	49	8.9	40	25	1.0	<0.1	<0.1	<0.1	0.2	<0.1	2.5
2/1/77	7.3	6.7	5.6	45	42	8.9	27	25	2.7	<0.1	<0.1	<0.1	<0.1	<0.1	2.1
2/2/77	8.4	6.6	5.3	40	40	6.4	23	21	1.0	<0.1	<0.1	<0.1	<0.1	<0.1	1.7
2/7/77	7.7	8.0	6.8	30	34	7.9	17	18	1.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.2
2/8/77	6.9	7.8	6.1	35	30	12	17	19	3.4	<0.1	<0.1	<0.1	0.2	<0.1	2.3
2/9/77	10	7.5	5.7	32	40	8.2	22	20	2.3	<0.1	<0.1	<0.1	<0.1	<0.1	2.0
2/14/77	12	9.4	8.2	40	37	5.3	26	19	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	2.3
2/15/77	15	8.6	7.4	51	49	8.6	27	37	3.0	<0.1	<0.1	<0.1	<0.1	<0.1	2.2
2/16/77	11	-	3.2	37	-	5.0	33	-	0.2	<0.1	-	<0.1	<0.1	-	2.1
2/21/77	5.7	5.9	6.4	24	28	9.1	14	14	1.8	<0.1	<0.1	<0.1	<0.1	<0.1	1.9
2/22/77	11	6.2	6.2	60	30	7.5	24	20	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	1.9
2/23/77	9.4	-	6.1	52	-	6.7	25	-	0.3	<0.1	-	<0.1	<0.1	1.1	2.4
2/28/77	8.9	-	6.6	41	-	5.7	22	-	0.4	<0.1	-	<0.1	0.1	-	5.4
3/1/77	8.0	7.4	5.7	46	41	6.6	23	20	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	4.4
3/2/77	9.1	-	7.8	32	-	4.2	32	-	4.2	<0.1	-	<0.1	<0.1	-	3.1
3/7/77	15	9.3	9.1	54	40	11	24	24	1.4	<0.1	<0.1	<0.1	<0.1	<0.1	3.2
3/8/77	8.5	7.6	6.3	47	44	5.7	24	23	1.6	<0.1	<0.1	<0.1	<0.1	<0.1	1.3
3/9/77	8.2	6.9	5.8	36	31	8.7	24	20	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	0.9
3/14/77	12	7.4	6.8	44	30	6.5	23	18	1.2	<0.1	<0.1	<0.1	<0.1	<0.1	3.2
3/15/77	8.4	12	6.0	49	45	7.0	23	20	0.7	<0.1	<0.1	<0.1	<0.1	<0.1	2.4
3/16/77	8.6	6.7	5.6	39	38	23	19	17	0.8	<0.1	<0.1	<0.1	<0.1	<0.1	1.6

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16. ABSTRACT
This investigation was undertaken with the objectives of reviewing the conversion of trickling filters at the Stockton, California, Regional Wastewater Control Facility from rock media to plastic media and to develop general design considerations for similar conversions which might be carried out elsewhere. Information on design of the secondary treatment modifications is presented, along with a description of plant construction and startup. The Stockton plastic media trickling filters are designed to operate in two modes: (1) to oxidize carbonaceous material during the canning season when plant loadings are high (design flow = 220,000 m^3/day or 58 mgd), and (2) to provide combined carbon oxidation-nitrification during the noncanning season when loadings are low (design flow = 87,000 m^3/day or 23 mgd). To evaluate plant performance, a special 1-yr sampling program was carried out. Plant performance for the 1-yr period is presented and evaluated. Operational changes intended to improve performance are described, and the results are discussed. Capital and operating costs for filter conversion are also presented. Based on information developed from evaluation of the Stockton plan and from review of other plastic media trickling filter plants, manufacturers' data, and technical literature, general design considerations are developed for converting rock media trickling filters to plastic media, including both process design and physical design.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Sewage treatment, *Trickling filtration, *Upgrading, Nitrification	*Synthetic (plastic) media trickling filters, *Rock media trickling filters, Canning wastes, Seasonal load	13B

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